A Handbook on Impounding Sac-Roe Herring

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March 1986

Canadian Industry Report of Fisheries and Aquatic Sciences No. 168

86-03536/

Canadian Industry Report of Fisheries and Aquatic Sciences

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Co-funded by the Fisheries Development Program

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Cat. No. Fs 97-14/168E ISSN 0704-3694

Correct citation for this publication:

Krieberg, H., J. R. Brett, A. Solmie, and R. A. Carter. 1986. A handbook on impounding sac-roe herring. Can. Ind. Rep. Fish. Aquat. Sci. 168: 46 p.

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ACKNOWLEDGEMENTS

The authors would like to recognize the substantial sponsoring involvement of R.H. McIlwaine, Fisheries and Oceans, Fisheries Development Program, in all of the studies from which this handbook is derived as well as the handbook itself. Some of those studies were carried out by D.F. Gillis and a number of his colleagues; the handbook has drawn freely upon their reports, and we acknowledge their significant contribution.

Herring impoundment studies at the Pacific Biological Station were stimulated by the Director, Dr. R. Beamish, and supported throughout; Drs. L. Margolis and J. McDonald gave the multi-year project its form and impetus. The success of the Pacific Biological Station research is owed in large part to the decade of previous experience with Pacific salmon at the Station's research fishfarm, and to the many improvements and suggestions contributed by its staff. All of the studies benefited from the input of the British Columbia commercial fishermen working on charter to the various projects. Carter Communications Ltd. of Vancouver B.C. co-ordinated the preparation of the handbook.

ABSTRACT

This handbook has been written for experienced fishermen interested in impounding herring. The impounding process it describes consists of –

- catching maturing adult herring by purse seine before they spawn and away from the spawning grounds
- transporting the herring live to a nearby holding site
- holding the herring in an impoundment while they mature normally
- harvesting and processing mature herring for sac-roe

The successful impounding of herring has been made possible through the discovery that, if herring are impounded, they will delay spawning for four to eight weeks after they mature while roe yield and quality remain high.

The handbook describes site selection, pond construction and techniques for capturing, transporting, holding and harvesting the herring.

Three methods of fish transport are reviewed: towed seine, live-barge and towable netpen. And three methods of impoundment are described: boom-log netpens, beach ponds and towable netpens.

The economic outlook for herring impoundment is good: the uniform maturity of impounded herring, the high survival rates, the excellent condition of the roe, the generally low operating cost and the option of handling smaller quantities of fish associated with this type of fishery all seem to promise profitable market prices.

While based on six years of research and reliable field experience, these methods have yet to be tested under full commercial fishing conditions.

Key words: sac-roe herring, impoundment, delayed spawning, economic outlook, towed seine, towable netpen, live-barge, capture, transport, holding, harvest

RESUME

Ce manuel s'adresse aux pêcheurs d'expérience s'intéressant à la mise en captivité des harengs. On y décrit le processus comme suit:

- La capture de harengs adultes en voie de maturation. Les poissons sont capturés à la senne coulissante avant le frai et loin des aires de frai.
- La transport des harengs vivants vers un lieu de conservation situé à proximité.
- La stabulation des harengs pendant leur maturation normale.
- La récolte et le traitement des harengs pour l'obtention des oeufs.

La garde en captivité des harengs a été rendue possible par la découverte que ces poissons, lorsqu'ils étaient gardés en captivité, retardaient leur frai de quatre à huit semines après être devenue matures et que le rendement et la qualité des oeufs demeuraient élevés pendant cette période.

Le manuel décuit le choix du site de stabulation, la construction de l'étang et les techniques de capture, de transport, de conservation et de récolte des poissons.

On y traite de trois méthodes de transport des poissons: la senne rémorquée, la barge pour poissons vivants et l'enclos en filet remorquable. Trois modes de stabulation sont aussi décrits: l'enclos en filet suspendu à des billes de bois, les étangs de plage et l'enclos en filet remorquable.

Les perspectives économiques de la stabulation des harengs sont bonnes. Le niveau de maturation uniforme, le taux de survie élevé, l'excellent état des oeufs, les coûts d'exploitation généralement faibles et la possibilité de traiter de plus petites quantités de poissons qu'offre ce type d'exploitation halieutique sont tous des facteurs qui semblent favoriser l'obtention de prix avantageux.

Ces méthodes, qui reposent sur six années de recherche et d'essais valables sur le terrain, n'ont cependant pas encore fait l'objet d'un essai dans les conditions réelles de la pêche commerciale.

Mots clés: oeufs de hareng, stabulation, frai retardé, perspectives économiques, senne remorquée, enclos en filet remorquable, barge de transport de poissons vivants, capture, transport, conservation, récolte

INTRODUCTION

BACKGROUND

This handbook has been prepared for prospective operators of sac-roe impoundments. It brings together the practical experiences gathered in the five-year research programme conducted by the Pacific Biological Station and the two field studies conducted by Gillis in 1979 and Gillis *et al* in 1981 on herring impoundment. Its purpose is to enable others to benefit from the experience and knowledge acquired from these studies. The studies were successful, and are now finished. Although the research findings of these studies were reported fully (see Reference Listing), many of the critical practical innovations were described only briefly for research purposes. Since almost all the research was conducted using regular seines and large commercial-scale operations, the experience will relate directly to future commercial developments. In this handbook we detail our insights, and make recommendations, which we hope will allow commercial operators to avoid some of the potential problems in sac-roe impoundment.

The research was aimed at developing techniques for handling, towing, impounding and harvesting sac-roe herring that would –

- protect traditional spawning grounds from the potential harmful effects of commercial seine fishing
- control the quality, volume and timing of roe production
- increase the value of the catch in roe, food and bait fisheries
- diversify the herring fishery
- turn the herring seine fishery into an economically secure and less competitive activity for the fisherman
- enable the processor to follow more orderly production schedules

The investigations show that, providing herring are caught long enough before they mature, holding them in an impoundment will cause them to delay spawning for as long as 4 to 8 weeks. The delay seems to be related to the unnatural environment of the pen, the generally small size of the school being held, the absence of natural spawn substrate and the presence of fouling on pond web and other potential spawn substrates. The delay allows less mature herring to catch up to the main group and results in 15 to 17% more No.1 roe. This is the primary advantage of impoundment. In addition, it allows the rate at which the fish are fed into the processing facility to be regulated.

The techniques described here have been found to be the best in terms of herring survival, roe quality and overall practicality. However, the findings have not yet been confirmed by observing actual commercial impoundments conducted by fishermen since a licence category for this type of fishery has not yet been established.

The handbook assumes that the reader is an experienced seine fisherman. Thus, we do not deal with fishing procedures except where they affect impoundment operations.

ECONOMIC OUTLOOK

Economic analysis indicates that impounding sac-roe herring is likely to be profitable for the pond operator. Such an operation should be of particular interest to fisherman using seines to catch sac-roe herring since it increases roe quantity and quality, making it a more profitable enterprise than at present.

An analysis done for the Pacific Biological Station (PBS) indicates that the landed price for impounded herring could be as high as for gillnet herring under normal conditions and perhaps higher if the males can be sold for bait. The latter is a realistic possibility since the carcasses from impoundments are of high quality. However, under less favourable circumstances, the price might be less than for gillnet herring since the roe will not be as uniformly large and thus will be worth less on the Japanese market.

The following table shows the estimated gross annual revenues of an impoundment operation assuming a 10% maximum total mortality (in keeping with the results of the Pacific Biological Station study) under three different price scenarios: (1) when the price is equal to the gillnet price, (2) when the price is based on the optimal roe production of PBS's 1982 study, and (3) when the price is based on the optimal roe production of PBS's 1982 study with the males being sold for sport bait.

Table 1
Annual Gross Benefits from Impounding Roe Herring

Mortality: 10% overall

Estimated Price of Impounded Herring (1982)	Estimated Annual Revenues (1982 dollars)		
	180 tonne	90 tonne	45 tonne
1. Equal to gillnet price ($918/tonne)	$182,000	$91,000	$45,000
2. Price based on optimal 1982 results, carcasses no value ($972/tonne)	193,000	$96,000	$48,000
3. Price based on optimal 1982 results, males sold for sport bait ($1,045/tonne)	$207,000	$104,000	$52,000

Source: Mary MacGregor. 1982. "An Economic Assessment of the PBS Roe Herring Impoundment Project", Pacific Biological Station Working Paper.

To determine the net revenue, the costs of the impoundment operation must be taken into account. Table 2 shows the estimated costs of operating an impoundment based on the Pacific Biological Station's experience with 20 to 40-tonne impoundments.

Table 2
Estimated Costs of PBS Type Impoundment Operation (1982 dollars)

A. Capital Costs	180 tonne	90 tonne	45 tonne	Expected Life
1. Floats for ponds (30 m x 20 m for 180 tonne) (15 m x 20 m for 90 tonne) (15 m x 10 m for 45 tonne)	$14,400	$10,100	$7,200	6 years
2. Nets for holding pen nylon, knotless, 2.5 cm stretch mesh	4,000	2,800	2,000	5 years
3. Nets for top	200	100	100	3 years
4. Mooring costs	1,000	1,000	1,000	10 years
5. Shack for watchman	2,000	2,000	2,000	10 years
Total Capital Costs	$21,600	16,000	$10,300	

B. Operating Costs	180 tonne	90 tonne	45 tonne
1. Seine charter @ $2,000/day	$14,000	$10,000	$8,000
2. Labour - 12 person weeks @ $432/week	5,200	5,200	5,200
3. Food ($20/day)	1,800	1,800	1,800
4. Harvesting costs	unknown	unknown	unknown
5. Miscellaneous	5,000	5,000	5,000
Total Operating Costs	$26,000	$22,000	$22,000

Source: Mary MacGregor. 1982. "An Economic Assessment of the PBS Roe Herring Impoundment Project", Pacific Biological Station Working Paper.

The capital costs are based on the cost of constructing a towable netpen using decked floats. The costs for an impoundment operation using boom-log netpens would be considerably lower, probably totalling about $5,000 (in 1982 dollars).

As this second table indicates, for a 180-tonne operation, the operating and capital costs in the first year would be $47,600. And, as the first table indicates, the gross revenues would be between $182,000 and $207,000. This gives a net income of between $134,000 and $169,000, a very good return on a modest capital investment of $22,000. Over 10 years, with a discount rate of 10%, the present value of revenues would range from $1.2 to 1.4 million; the present value of the capital costs would be at most $34,000 and the present value of the operating expenses would be $176,000. Such an operation would clearly be a decided success from the operator's standpoint. Even the smaller 45-tonne operation would bring in high net benefits for the operator.

OTHER BENEFITS

In addition to monetary benefits, an impoundment operation would minimize the risk facing fishermen in the highly competitive fishery openings. It would also enable the fishing of small stocks of herring that are currently unused. One or two vessels fishing for an impoundment could be permitted to fish a small stock whereas the large numbers of seiners that would show up for an opening could not, due to the risk of wiping out the stock.

MARKETS

The market prospects for roe from impounded herring are good. Roe herring from PBS impoundments have been processed commercially for 2 seasons and have proved very acceptable. And the possibility of the males being frozen and sold for sport bait is promising given their low scale loss and excellent condition. (Since 1981 sport bait prices have remained high averaging up to $0.40 per pound.) But the prospect of roe herring carcasses being sold for food is poor. At about 3 to 4%, their oil content is too low for European and Japanese markets, and they are unlikely to sell for use in high quality pet or fish meal. The recent development of silage techniques to produce fish feed for aquaculture may however permit some cost recovery from sac-roe herring carcasses.

PROCEDURES

The procedure for impounding sac-roe herring consists of the following steps:

1. Preparation. (This includes selecting the means of transporting the herring from the fishing grounds to the impoundment site, selecting an impoundment site and constructing the impoundment.)
2. Capturing the herring.
3. Transporting the herring from the fishing grounds to the impoundment.
4. Holding the herring in the impoundment.
5. Harvesting the herring once they have matured.

We describe each of these steps in detail below.

PREPARATION

A successful herring impoundment demands thorough planning. This involves studying herring stocks in the proposed area and evaluating available equipment, materials and finances. Once this is done, you can decide on the type of transportation you will use and on the capture and holding sites. You will also need to obtain the necessary licences and approvals from appropriate agencies.

The following sections explain the steps involved in preparing for an impoundment. These steps need not be completed in the order presented here.

Selecting a Means of Transport

The means of transporting herring to a holding pond affects the quality and volume of roe you obtain at harvest. And the operating range limitations of the methods affect the choice of catching and holding sites. We describe here the three methods available:

- towed seine
- semi-submersible live-barge
- towable netpen

Towed Seine: Seine towing is the method currently used by B.C. spawn-on-kelp fishermen to transfer live herring from the capture site to a seapen containing kelp hung on ropes. Before the seines can be used for transporting the fish, they must

undergo some rigging changes. These are shown in Figure 1 and described in the transport section under 'Towed Seine'.

Where the herring can be seined close to the impoundment and where tidal flows help to move the loaded seine to its destination, seine towing can be the most cost-effective method of transporting the herring.

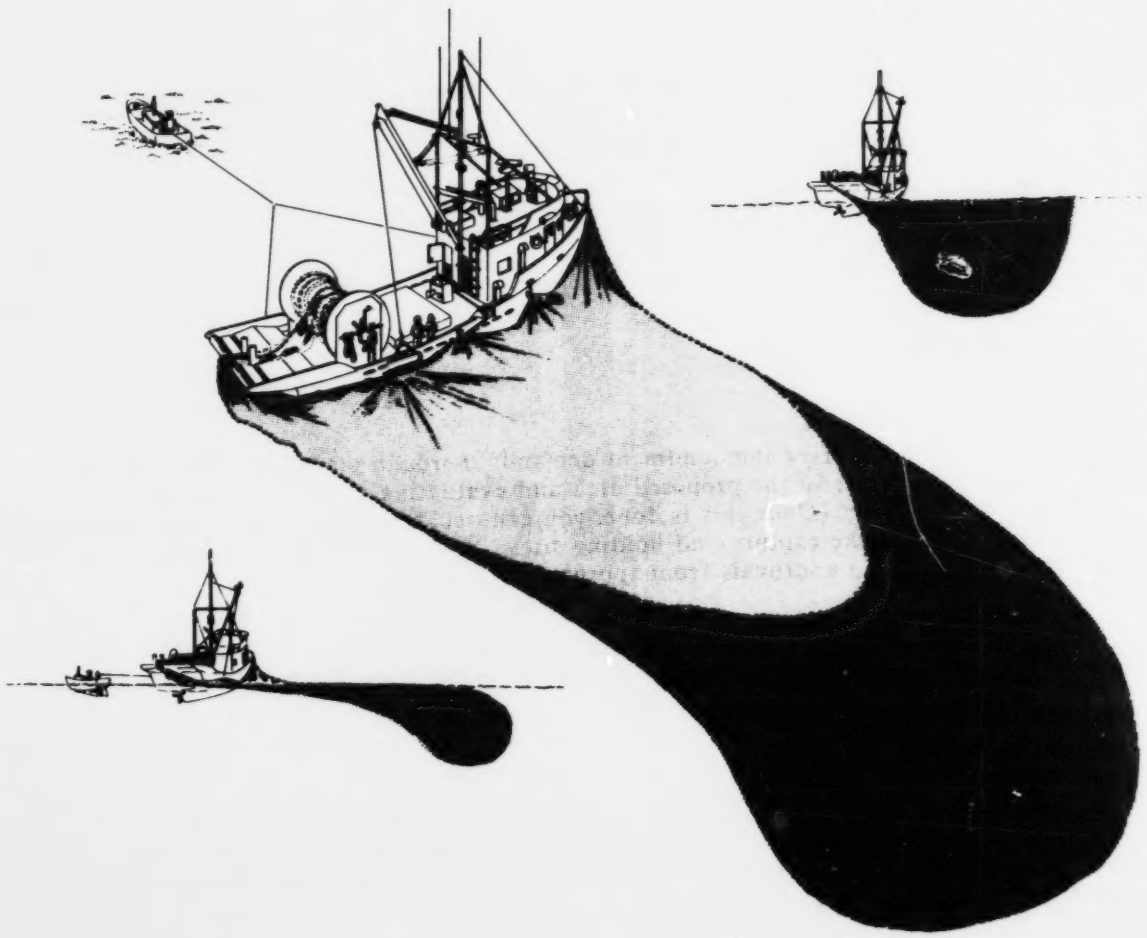

Fig. 1. Towed seine (insets show seine shape after pursing (top) and during towing (bottom))

But seine towing is unsuitable for distances much over 1 nautical mile, since the herring progressively become damaged by the seine net and thus suffer serious mortality (as high as 21 to 40% within a few weeks). So, when using this type of transportation, you must either make a short tow or travel at a slow speed (0.2 to 0.25 knots). Even then, the tow should be no longer than 3 or 4 hours.

Furthermore, if the herring do not 'follow' the vessel when towing begins, some or all of the set may have to be dumped, or the vessel may find itself being towed off course by the herring.

Semi-Submersible Live-Barge: Of the three types of transportion, the semi-submersible live-barge gives the best results because the fish get a free ride (i.e. they do not have to swim as they do in towed seines and netpens) and because they are protected from predators.

This results in the following advantages:

- a high survival rate, over 99%
- a faster travelling speed; barges can move at a top speed of 3 to 5 knots
- an extended range of operations, up to 30 to 50 km

A live-barge consists of an unpowered displacement hull (Fig.2) equipped with ballast tanks, which, when pumped dry, allow it to ride on the surface of the water, and when flooded, submerge the vessel 2 to 4 m.

Fish enter and leave the flooded barge through a flanged loading gate in the stern. Screened water-exchange ports are provided along the sides of the vessel. Sliding doors in bulkheads can be used to control the distribution of the load.

The low mortality rate and extended operating range associated with the live barge must be weighed against its relatively high capital cost and present small capacity. Barges currently available are of 50 to 70 tonnes displacement when flooded, and carry loads of 5 to 7 tonnes of live herring. The cost of such a barge can run as high as $60,000 (Canadian) per unit; larger units have not been built. Whether this cost can be lowered through subsidized or cooperative ownership remains to be seen. A live-barge for herring could be used at other times for transferring sea-farm salmon and commercial or sport bait fish, or for multiple tows from a distant satellite netpen.

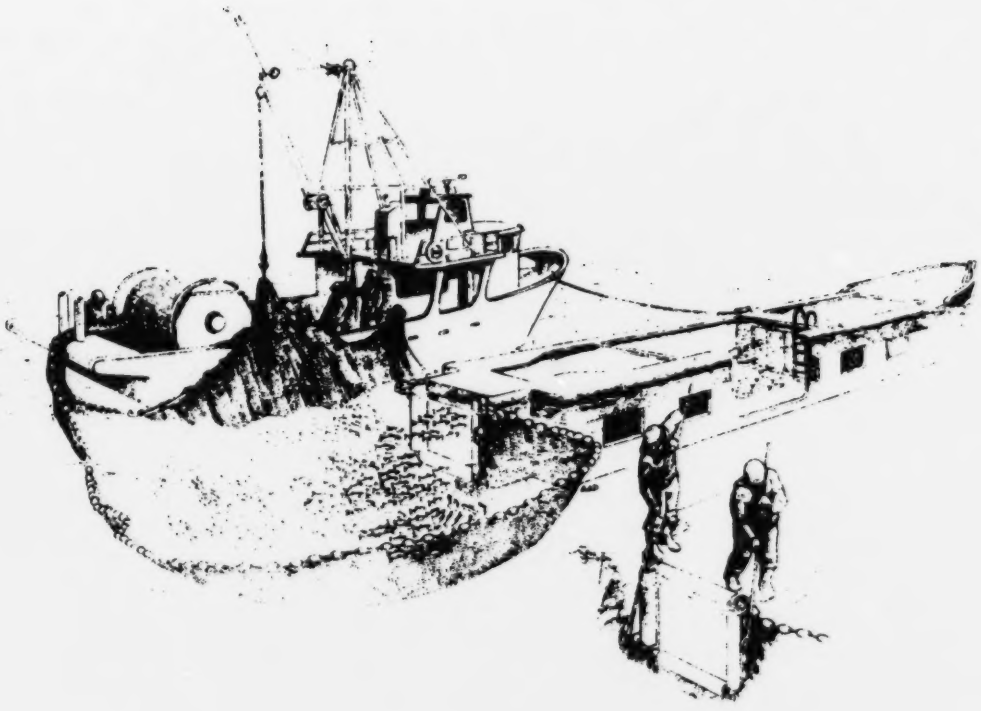

Fig. 2. Live-barge (in the process of loading fish from a seine. Barge as designed and operated by W. Cameron, Madeira Park, B.C.)

Towable Netpen: The towable netpen unit (Fig.3) was developed at the Pacific Biological Station to transport and hold live Pacific herring in B.C. inshore waters. Made from commercial marina float components, the structure performed almost as well as live-barges and much better than towed seines.

By making relatively minor changes to its weights and rigging, a floating netpen can be transformed into a towable netpen. In 1983, the total cost of the alterations involved in modifying the netpen amounted to less than 8% of its capital cost.

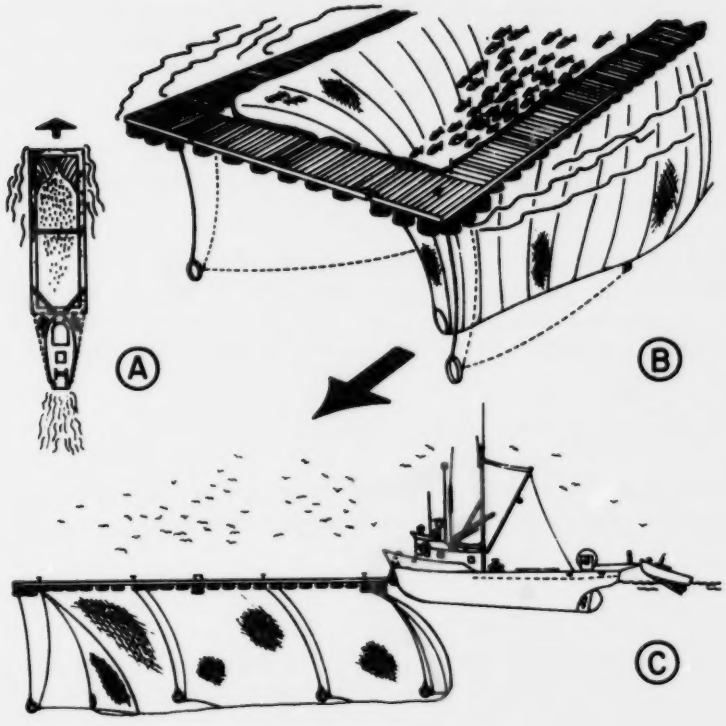

Fig. 3. Towable netpen. (A) Top view, spring lines for pushing, frame reinforcement (B) Netpen under way showing dynamic bow details (C) Netpen under way, side view.

Source: H. Kreiberg, J.R. Brett and A. Solmie. 1984. Roe Herring Impoundment Research–Report on the 1983/1984 Studies. Canadian Technical Report of Fisheries and Aquatic Sciences No.1329.

Towable netpens have the following advantages:

- Low fish mortality. With appropriate handling, the towable netpen can provide a high survival rate of up to 97%. The box-like shape of the netpen reduces the amount of injury to fish from predators and contact with netting. Sea lions cannot climb over the high raised-deck float as easily as they can over the corklines of towed seines, and they do not disturb the herring by surfacing for air from under the mesh as they do with a towed seine.

- Cost-effectiveness. The netpen's twofold use as a transportation and holding unit, combined with the low cost of the towing modifications, makes the netpen a comparatively inexpensive method of transporting herring. Furthermore, the capital cost of a towable netpen is offset by its providing a safe and roomy work platform, particularly at night or in bad weather.

- Extended Range of Use and Travel. The netpen's design makes its use flexible. You can break the float into sections, which may be rafted together for convenient towing or used to house a number of smaller groups of fish. When towing must be halted temporarily, the netpen can be left safely at anchor or adrift. The rigid structure permits easy handling, and it can be towed at speeds approaching the maximum that herring can sustain comfortably (about 1 knot). The netpen is also considered useful for the culture and transport of other fish species such as salmon.

- High Capacity. Netpens can be built readily to transport and hold 30 to 40 tonnes of herring per unit.

- Quick and Easy Handling. Loading the netpen with caught herring is as easy as loading a live-barge or preparing a seine for towing. A small crew of 2 or 3 people can easily take samples, remove dead fish and make transfers. The decked float, as well as providing safety for the crew, can reduce the need for a support vessel.

- Durability. The towable netpen has an expected life span of 7 to 10 years.

Table 3 compares the use of the three methods of transportation during an experimental impoundment in Whaleboat Passage in the B.C. Gulf Islands.

Table 3
Comparison of 3 methods for transporting live herring
to the Whaleboat Passage holding site

	Barge	Netpen	Seine
Weight of herring (tonnes/trip)	3	21.0	32.0
Density in transit (kg/m^3)	22.2	9.4	N/A
Distance covered (naut. miles)	1.5	1.5	1.2
Speed over bottom (knots)	3.5	0.5	0.2
Tow duration: load, rig (hours)	1.0	1.5	0.5
transit (hours)	0.4	3.0	6.0
Survival to 8 weeks (%)	99.6	97.0	79.6

Source: H. Kreiberg, J.R. Brett and A. Solmie. 1984. Roe Herring Impoundment Research–Report on the 1983/1984 Studies. Canadian Technical Report of Fisheries and Aquatic Sciences No.1329.

Selecting a Site

Selecting an appropriate holding site depends on –

- the fishing stocks in the area;
- characteristics of proposed sites;
- regulatory compliance.

Available financial resources and manpower will also affect the choice.

Fishing Stocks: Location, composition and historical movement of herring stocks are the decisive considerations in selecting potential sites. As an experienced fishermen, you will already have an idea of where the most promising stocks are to be found. You must relate their location to the proposed sites as well as to the capacity of the transportation method you choose. For example, if you decide to transport the herring in the traditional manner–by towed seine–you will probably have to select a site within one nautical mile of the proposed fishing grounds.

You will also have to consider the composition of the stocks that will be in the area during the impoundment. Basing your selection on existing local knowledge regarding the characteristics of herring in the chosen area will help to avoid capturing herring of mixed groupings, and thus of widely varying sizes. In an impoundment, you can deal with the different rates of maturation by delaying the harvest until the majority of fish have matured, but you cannot make up for mixed sizes and their associated increase in processing costs. Also, since grading is partly a function of the roe size, small fish reduce the yield of top-grade roe.

Site Characteristics: The tides, currents, water depth, accessibility and shelter at each potential site will also need to be examined. Suitable holding sites should have as many as possible of the following characteristics:

- an adequate low-water depth of 3 m or better under the bottom of netpens
- tidal flushing to maintain good water transparency
- proximity to the fishing area and a processing plant
- distance from known sites of wild herring spawning and predators (e.g. seal and sea-lion rocks)
- shelter against heavy wave and wind action
- currents of not more than 1.5 knots

The ponds need to be located so you can easily get to them from the fishing area and from them to the processing plant. If sites are difficult to reach, they will entail a loss of time, deterioration of harvest during long transits or higher packer fees.

A pond should not be situated immediately adjacent to a known spawning area or where the prevailing tides can carry milt to the pond from a wild spawning area since milt can cause the impounded stock to spawn.

Holding ponds can be built to withstand some exposure, but should not be located where they will be subject to high wind or wave action. Those used in fieldwork by PBS were rated for 2-m swells and a 1-m chop. A log breakwater should be installed to protect the ponds where some heavy weather is expected.

Currents and tides should be determined as exactly as possible. In general, netpens should not be exposed to currents of more than 1 to 1.5 knots. Stronger currents will cause the netpen to billow and distort, reducing space available for fish to swim in, and putting excessive strain on moorings and pen construction. Fouling magnifies problems of current drag even at very low velocities.

Regulatory Compliance: Currently, no licence category exists for herring impoundment. Once a category has been established, however, fishermen planning on impounding herring will likely have to obtain approval on the location and method of impoundment from the federal fishery management office supervising the area.

Where applicable, clearances will also have to be secured from uplands owners and the Provincial Ministry of Lands, Parks and Housing concerning foreshore leases, and from the Federal Department of Transport regarding Federal Shipping Act requirements for a floating moored obstruction and notices to mariners.

The steps for acquiring a foreshore lease are given in Appendix 1.

Constructing the Holding Pond

The next sections describe the construction of three different types of holding ponds: boom-log pens, beach ponds and towable netpens. All ponds must be constructed to provide enough lead time to allow the nets to foul since this appears to be a key factor in preventing the herring from spawning. In locations where the fouling rate is minimal, you may have to build the pond two or three months before the impoundment is to take place. Fouling on the upper web (for the first metre) has proven to be adequate.

Boom-log floating pens: Boom-log floating pens (Fig.4) may be built on site, or prepared in advance. Prefabricated pens have been found to have several advantages over constructing pens at the holding site:

- They can be installed in various locations if suitable herring are found nearby.
- The pens can be set up quickly. Given suitable logs or boomsticks, which are generally available, a log frame can be assembled and the prefabricated pond web installed in a day by three men and a seine boat.

- The pens are portable. The boomstick frame can be easily towed using a towing bridle attached to two corners of the pond. (Towing a pond by one corner tends to collapse it). If web has already been installed, it can be pulled up onto the logs and tied. A pen without web can be towed by dropping one boom-chain so that the four sticks tow in a line.

Thus, we describe here a method for constructing a prefabricated log-boom pen.

First, the web, lines and booming hardware are assembled and stored where they are accessible. The nets should be white to discourage diving birds from picking through them and should be made of knotless nylon with a 22-mm stretched mesh rather than tarred nylon seine web to minimize damage to the herring. The net may be constructed by lacing web strips together into a single panel, which will result in a baggy, generally hemispherical underwater shape. A becket line is hung from the bottom of the web with 5-cm nylon rings at 2.5-m intervals. A 1.3-cm nylon line runs through the rings to serve as a purse line. The bottom of the pond can then be closed by drawing up the purse line. The nylon rings afford easy passage of the purse line ensuring that it closes evenly and tightly. This type of netpen construction is used in spawn-on-kelp impoundments, where high mortality is often seen. Release of the purse-line permits quick clearing of dead fish from the netpen, although the dead continue to foul the area, especially if it is shallow.

Alternatively, web can be sewn into a floor panel and a wall-panel, which are then stitched together to form a box. This type of netpen is less simple to build, but it hangs much better under water, using some counterweights at corners etc, and there will be little or no baggy excess to create folds in which the fish will descale and smother. The web should not be tapered toward the bottom, so that if the pond has to be towed empty, the web can be pulled up and piled on top of the perimeter logs.

Suitable boomsticks can be towed to the ponding site. They should be flat notched on the ends to interlock with one another and then arranged to form a floating square (a 20-m square pond has been found to be suitable). The more buoyant logs should be placed under the less buoyant to give them support. To provide a safe working platform, the working front should be constructed of double logs lashed with wire. The corners are lashed together with two to four wraps of cable held in place with boom staples. To tighten the cables the corners will need to be lifted. This can be done using a double block attached to the boom of a fishing vessel.

Once the logs have been lashed to form a rigid square, the pond web can be suspended inside the floating boomsticks, hung from 1.3-cm nylon line. The line can be nailed or stapled to the inside of the boomsticks except for a 3 to 5-m gap left for the gate.

If the netpen is not of the box-type construction, a weight, such as a piece of boom chain should be hung from the centre of the net and supported by a line to the surface secured to a large float ("scotchman"). The length of this line determines the depth at the centre of the pond, usually 5 to 8 m. By hanging additional weights (such as rocks in onion sacks) at the corners and along the sides, the shape of the pond and the depth of its walls can be adjusted. The web should not touch the sea bottom at any time.

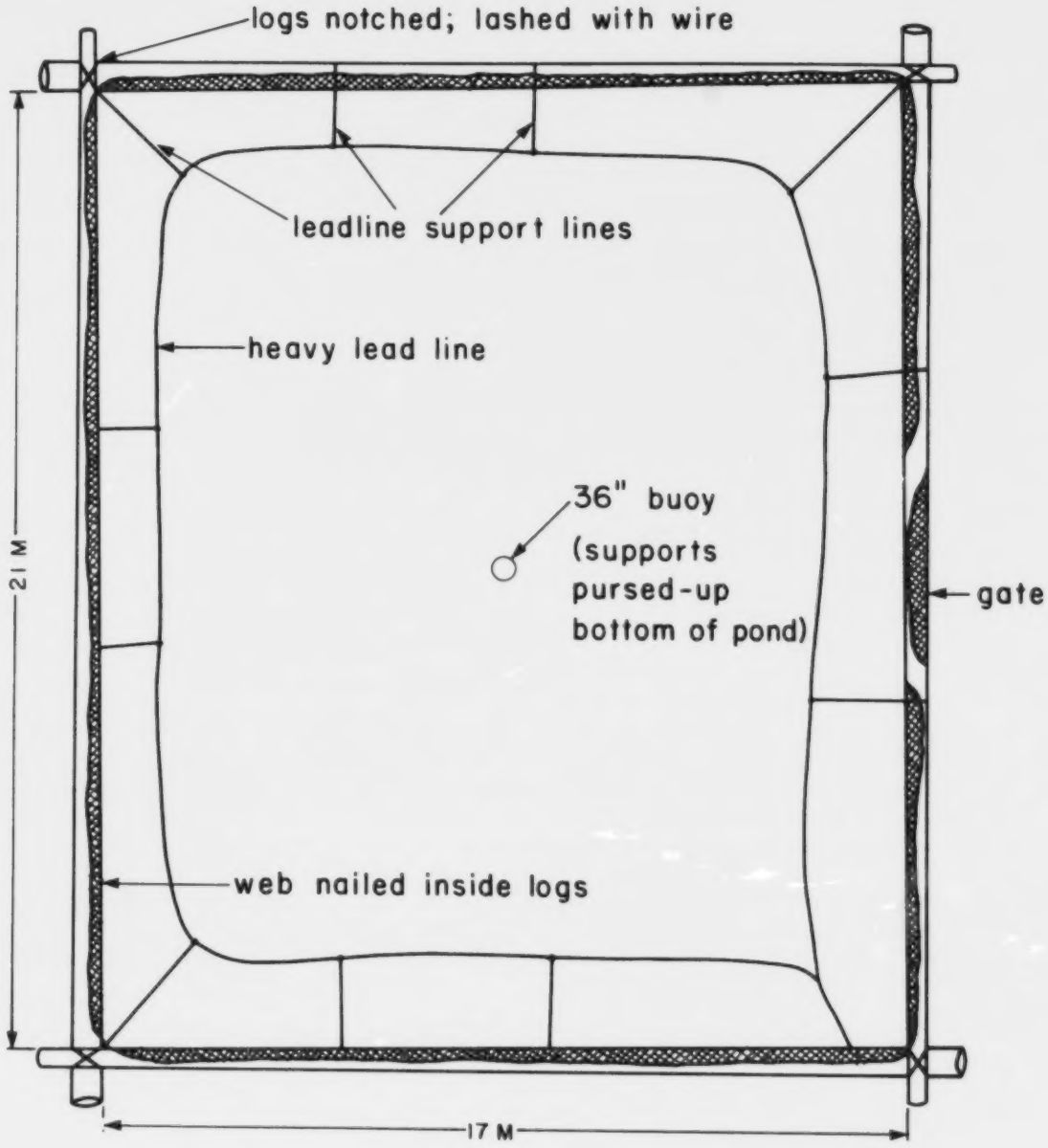

Fig. 4. Boom-log floating pen.

Source: D.J. Gillis. 1979. Ponding and Other Factors Affecting the Quality of Herring for the Food Industry. Department of Fisheries and Oceans Industry Report No.109.

The gate can be constructed by passing a section of the pond net to the outside of the log structure, making two vertical cuts in the web on either side of the gate, and lacing one tapered web panel into each cut. This provides a gate about 10 m wide, which hangs down nearly 10 m during fish transfer. A piece of lead line should be laced to the gate to aid in its sinking.

The pen may be anchored with a number of moorings pulling in opposing directions, or it may be left to swing on a single mooring.

Day beacons and lights must be installed to conform to the Collision Regulations of the Canada Shipping Act.

Beach ponds: Beach ponds (Fig.5) can enclose large volumes of water with relatively little ponding material, and hence cost less for a given volume. Few bays close to fishing grounds are suitable for beach ponds; however, if a bay is suitable, beach ponds can prove a viable alternative to boom-log pens and towable netpens.

The frame for the pond is constructed of logs, bound together with wire. Usually two sides will have to be constructed, in which case a short log should be used to triangulate the junction between the two sides. Again, to provide a safe working platform, the working front should be constructed of double logs lashed with wire. The frontal logs must be firmly anchored or attached to the beach by lines. These logs must not move appreciably while the fish are being transferred to the pond.

Webbing is hung inside the frame and held against the sea-bottom by heavy lead line or by chain when the web traverses rocky bottom. Heavy rocks will likely need to be placed along the lead line to prevent its being lifted off the bottom by currents, particularly once the net has fouled. You must consider tidal levels when determining how much scope should be built into the pond web, since the lead line must not lift from the bottom as the tide rises. Two fathoms more web than the high tide water depth would be a reasonable safety margin. The net must be continuous to the high tide line on the beach. As with floating ponds, the web should be white and made of knotless nylon with a 22-mm stretched mesh. Since beach ponds are usually quite large, substituting tarred web is sometimes acceptable if there is no chance that fish will rub against it.

The gate can be constructed in the same way as for log-boom pens described above.

Day beacons and lights are also required.

Constructing the pond can take considerable time, up to 120 man-hours, and may require two seine boats, two power skiffs and two dead skiffs.

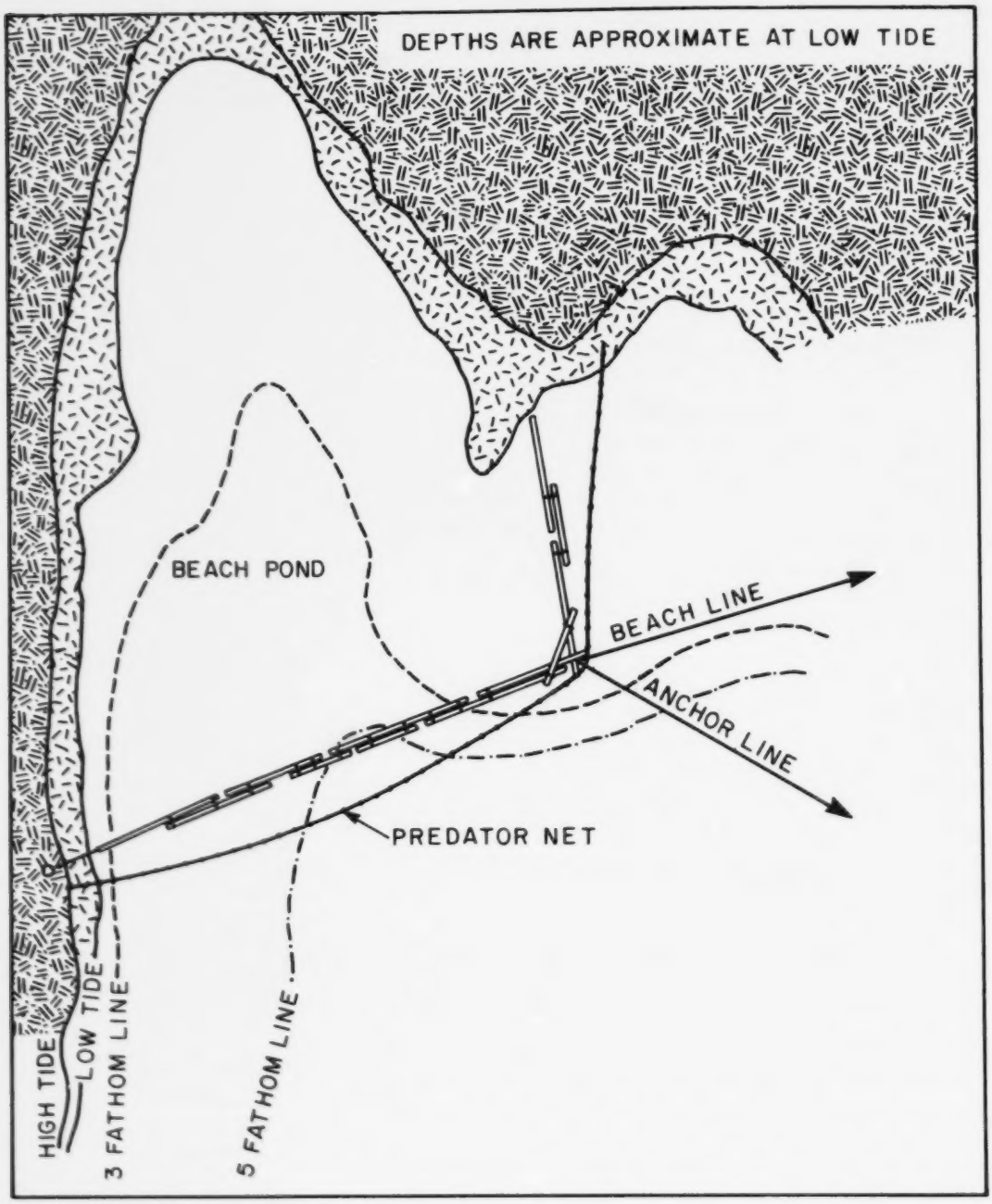

Fig. 5. Beach pond

Source: D.J. Gillis *et al.* 1982. Herring Impoundment and Pumping Operations. Canadian Industry Report of Fisheries and Aquatic Sciences No.130.

Towable netpens: A float measuring 30 m by 21 m and capable of housing two 28 m x 8 m x 8 m netpens has been found to be highly suitable for impounding herring. Such a float can be constructed from sections of marina floats (e.g. Topper Industries T-23-F design) with additional floatation added to accommodate increased weight from mooring systems.

A gate should be provided in one end of the float measuring approximately 6 m long, which can be removed from the float structure to allow for transferring herring either from a seine or from a live-barge. This section of the float should be held in place by a pin and bracket system to allow for both easy removal and sufficient strength to hold the float configuration during unfavourable weather conditions at the mooring site.

White 210-30 knotless nylon, 22-mm stretched mesh has been found highly suitable for constructing the pen. The web is hung in a box-like shape, which is maintained by nylon control lines (downhauls and lifting lines) run through rigging-weights and tensioned from the float deck. The following lines have been found to be suitable: a 16-mm borderline, four 13-mm corner lines, two 10-mm transverse rib lines (9 m apart and led across the bottom of the pen), a horizontal 10-mm rib line placed halfway down the side of the netpen, and finally a 50 kg per 100 fathom lead line around the bottom perimeter of the netpen. Figure 6 shows how a netpen is kept taut and square.

Once the pen has been towed to the impoundment site it should be securely anchored. Eight 360 kg mooring anchors kg on 13-mm mooring chain have worked well for a 30 m x 21 m float. The chain should be about 1.5 times the high-water depth at individual anchor locations. The anchor arrangement shown in Figure 7 has been found to be effective for mooring large pens.

Chafing planks should be set under the chain at points where the chain bears heavily on the float.

As for the other ponds, day beacons and lights must be installed.

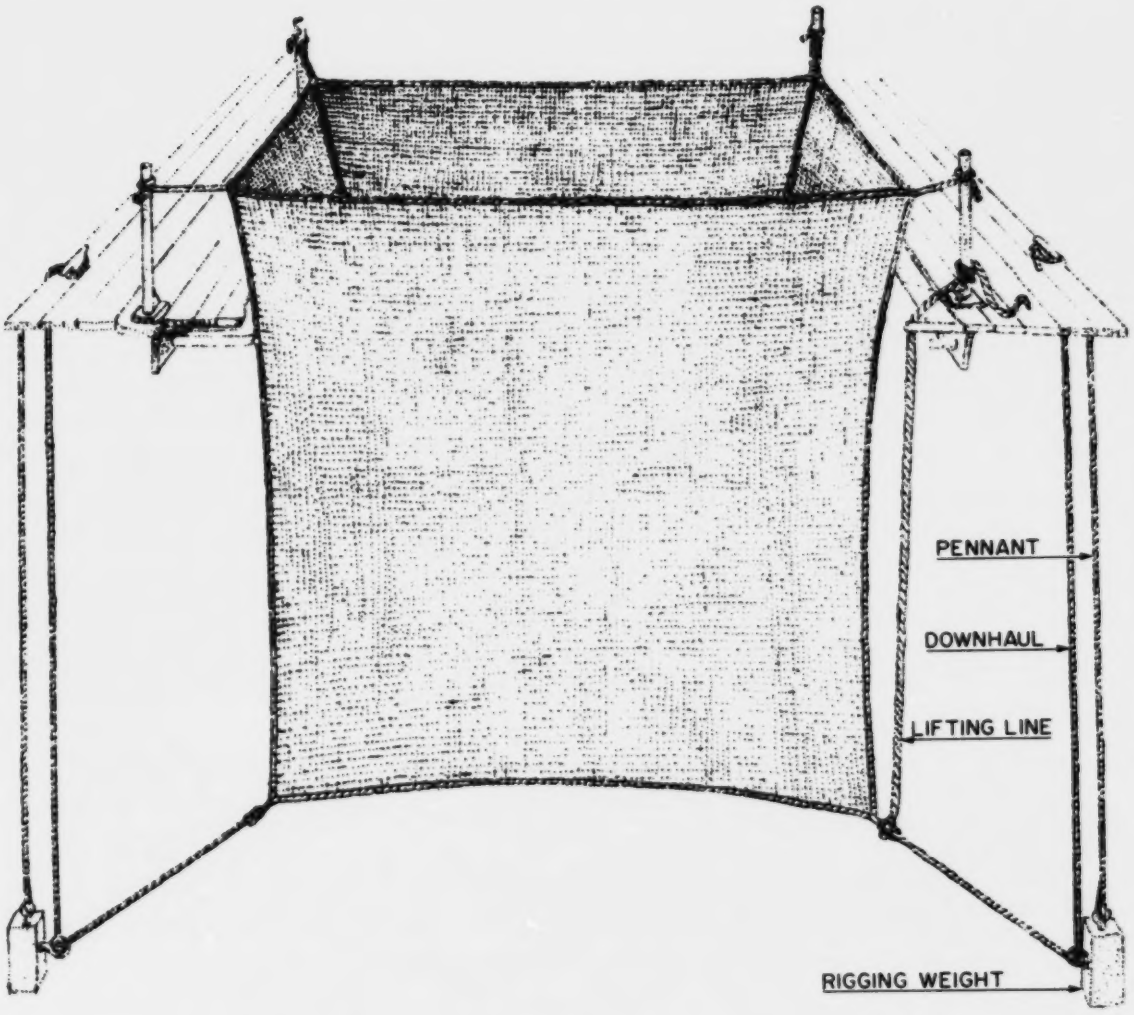

Fig. 6. Keeping a netpen square and taut.

Source: W.A. Kennedy. 1978. A Handbook on Rearing Pan-size Pacific Salmon Using Floating Seapens. Fisheries and Marine Service Industry Report No.107.

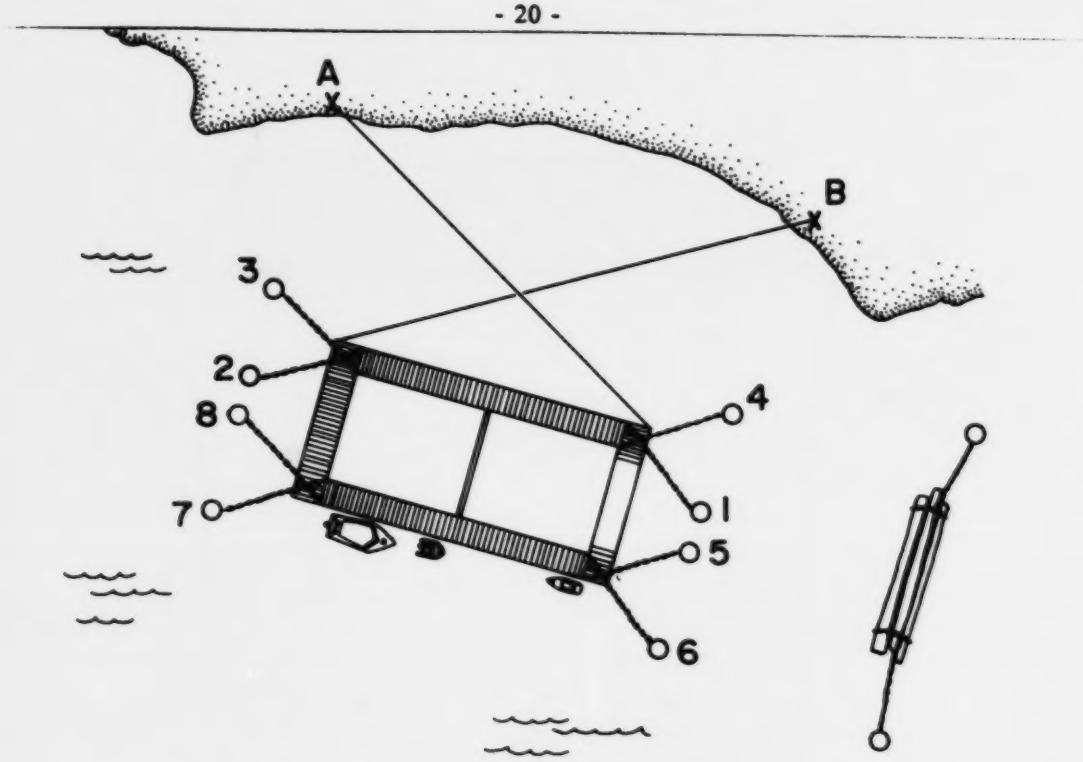

Fig. 7. Mooring system and breakwater for a floating pen. Temporary springlines A and B were removed once the anchors were set. The anchors are numbered in the order set. Not to scale.

Source: H. Kreiberg, J.R. Brett and A. Solmie. 1984. Roe Herring Impoundment Research Report on the 1982/1983 Studies. Canadian Technical Report of Fisheries and Aquatic Science No.1261.

CAPTURE

Capturing herring for impoundment is essentially the same as seining for traditional roe herring. But some aspects are important for the future survival of the herring and for the overall success and ease of the operation. This section describes the equipment, the timing and techniques for capturing and sampling.

Equipment

Normally, standard west coast commercial purse seiners equipped with regulation 25-mm stretched-mesh seines (not exceeding 430 m x 60 m) are used to catch the herring. A side scanning sonar and depth sounder may be used to locate and calculate the tonnages of schools in the area. Another craft, such as a seiner or smaller vessel, may be useful for support. A second power skiff is often helpful in manoeuvering a towable netpen or live-barge, or simply as a standby while towing a seine.

Timing

It is important to be familiar with the herring stocks you intend to fish so that you capture them at the right time. Research has shown that, if herring are caught too close to their spawning date, e.g. 1 week before spawning, the delayed-spawning effect does not work very well and some of the fish spawn, seriously affecting the value of the harvest. Early capture, up to 10 weeks before expected harvest time, is highly desirable, and at a minimum, you should plan to hold the herring for at least 4 weeks before their normal spawning date to be sure of the delay-of-spawning effect upon which the harvest depends. You must also allow for winter weather delays, equipment breakdowns and the irregularity for which herring are known. Weather conditions for fishing are more critical than for normal seining due to the need to transfer the catch safely to a transport device. A further benefit to fishing earlier is that the herring are less 'heavy' with roe, and will be easier to handle. In general, you should allow a safety margin of 4 weeks in addition to the 4 weeks the fish are to be held.

Method

The technique you use in making your set affects the roe yield considerably by influencing the composition of the catch and the survival to harvest. It must involve gentle, quick and minimal handling of the fish to avoid stress and scale loss.

Stress can cause herring deaths even when the fish show no signs of external damage. So stress must be avoided to ensure high survival rates.

Scale loss is a serious problem since it allows bacteria to get at the skin and spread under the healthy scales, and it produces a "leak", which results in excessive water loss. Under normal circumstances, a fish's blood is less salty than its saltwater environment, and therefore, due to osmosis, the fish constantly lose some water mostly through the gills. But a new leak means added work for the internal mechanisms that act to retain water. If the scrape is serious enough, the fish cannot cope with it, and will die.

Small, rather than large, sets should be made since they reduce crushing and rubbing of fish against the web by those above them, and thus minimize scale loss.

Fishermen often set as soon as the tops of the herring schools come up into reach of the seine. But waiting until a school of herring rises close to the surface will enable you to fish within the midst of the school, where the larger fish congregate, rather than skimming off the top, which often consists of smaller fish and fewer females. In addition, by using the powerskiff to push the seiner into the set before pursing, you can fish more deeply and hence more productively.

A knotless bunt in the seine will help you to handle the fish with a minimum of scale loss. Brailers and impeller-driven pumps should not be used to capture or herd the fish since they stress and descale them. Venturi-effect fish pumps have not been used in any impoundment research to date; hence, we make no specific recommendation about them.

Sampling

Once you have made the set and before you dry up the seine, you will need to make one of the most important decisions in an impoundment operation: whether to keep the set or release it and try again. Sampling should be carried out at this time to check the following:

- Ratio of male to female herring, which indicates the volume of roe yield. A catch of less than 50% females would likely be improved on by setting again somewhere else, and might only be kept if the size of the females were very large, offsetting the low number of roes.

- Size of roe, which can be roughly determined from the length of the fish or by gutting the fish. The size indicates the potential quality of roe and the degree and uniformity of maturity.

- Size of the females, which is a guide to the eventual proportions of No.1, 2 and 3 roe. A small female may never be able to produce the 10-cm roe-sac necessary to qualify for No.1 grade.

Since schools of herring of very mixed maturity will likely not mature at the same time, you should try to find herring as close to uniformly developed as possible. No real guidelines can be given for making this decision; it is a matter of the skipper's judgement and experience. But, even if the herring are very mixed in maturity, the impoundment will allow the late maturing ones to catch up. It does dictate a later overall harvest date, which may have drawbacks with respect to price trends and other external factors.

Samples are generally taken from the bunt of the seine or by dip netting fish from folds in the net while drumming in the seine. When dip netting, you will obtain a more representative sample by reaching out as far as possible into the body of the seine and withdrawing fish only from boils.

Frequently, to avoid stressing the fish, the seine is pursed only until the rings have been raised. While providing the maximum amount of room for the fish, this arrangement does make it difficult to obtain accurate samples from the deck of the seiner. In this case, the skipper must exercise judgement and experience in drumming up some of the seine to achieve a compromise between a good sample and high stress for the fish.

It is usually possible to obtain good samples while transferring fish from the seine to a live-barge or towable netpen since some crowding is unavoidable. It may therefore be acceptable to make preparations for transferring the set before beginning to drum. If the samples prove to be poor, only 1 or 2 hours of fishing time will have been lost. (Precautions should be taken to avoid actually loading any fish into the transport device until the sampling results are evaluated.)

Whichever sampling method you use, the samples must be as representative of that group as possible. To this end, you should –

- examine at least two samples
- take samples as large as practical (20 to 40 kgs should be adequate).

Bycatch and Predators

Sealions, and to a much lesser degree, dogfish, are the only predators to cause serious problems during catching and towing. They stress the herring and deform or tear the nets.

Predators and other bycatch should be removed from the catch as soon as possible. The following devices and techniques have been used, with some success, to keep predators, especially sealions, away from the net.

Underwater seal bombs: Set to explode in the bottom of the seine just after pursing, these bombs will sometimes drive the sealions out over the corkline without causing harm to the catch. Extensive use in the same set is not recommended, but 2 or 3 bombs may prove beneficial.

Surface bombs: Similar to rifle shots, these bombs cause the predators to dive. However, if the predators are within the seine, this tactic could cause a frightened sealion to burst through the web underwater.

Plungers and pike poles: These devices can occasionally be used to chase out tired sealions once the seine has been partially drummed aboard but before transfer has begun.

Light and sound diversions: Turning on lights, making sounds aboard a decoy vessel or using an underwater speaker to play killer whale sounds are other possibilities. Underwater emitters of high frequency white noise do not affect herring, but have sometimes been successful in discouraging seals. They have not worked well with sealions.

A more effective method of keeping the sealions away from the nets is to chase them with a power skiff; a second skiff should circle on the far side of the net from the seiner, as sealions tend to gather in this area. Experience indicates that sealion sounds of distress have no effect in discouraging other sealions.

TRANSPORT

Once a suitable set of herring has been made, the fish must be transported to the holding site. This is the most sensitive phase of the impoundment process.

The following section describes briefly how to move the fish from one enclosure to another and the three methods of transporting fish to a holding site: towed seine, towable netpen and live-barge.

General Rules for Transferring and Towing

Transfers

- The fish should be allowed to swim from enclosure to enclosure to avoid physical damage. You should provide an effective opening of about 8 to 10 m wide and as deep as possible. When sewing together two nets or netpens for a transfer, you must link roughly three times as much length as you want for the opening. Much of the temporary joint remains at or near the surface, where the fish tend not to go. Even if two weights are used to sink the joint and make a square gate underwater, an opening 8 m wide by 8 m deep will require over 24 m of laced joint. When the opening is too small, the fish are reluctant to enter, especially if they have to swim up over a sill, as in a barge, and they become injured from stress, crowding and rubbing against web.

- Transfers at night are generally less stressful and often easier. You can use an underwater light to herd the fish into the transport device, since they will swim away from the light. A spotlight above the surface may have the same effect, or the opposite. Brailers and pumps should not be used to transfer live fish unless exceptional circumstances justify the greatly increased scale loss.

- The gate should be patrolled with gaff and pike pole to prevent unwanted species from entering.

- Nearby engines such as skiffs and auxiliaries should be shut off and sudden movement or noises avoided during the transfer process. So any activities associated with discouraging predators (e.g. splashing with dipnets, plungers, or even seal bombs) should cease once the transfer process begins. Otherwise, a loss of income will result from stress-related deaths in the pond.

Tows

- When using a towed seine or towable netpen, which require that the fish swim to the holding site, you cannot travel faster than the herring's maximum cruising speed, about 1 knot. Herring forced to swim too hard, repeatedly frightened into boil-ups and handled roughly during a procedure, will develop lactic acid build-up in the muscles and blood. Unless given the opportunity to settle down and process the lactic acid, the herring's internal system will suffer impaired inefficiency, sometimes to the point of death. In its weakened state, bacteria may take over the fish's circulatory, digestive or other systems, eventually causing death.

  Scale loss must also be minimized. So check for loose scales in the water behind the net. If the loss is excessive, reduce the speed.

- If the tow extends into daylight hours, when wild herring normally descend into deep water, it may be helpful to discontinue towing until it becomes dark again to reduce stress for the fish.

- An effort should be made to become familiar with tidal currents along the tow routes through observation, fishing experience, contact with log-boomers, etc. since this knowledge can substantially reduce the time spent towing. Less towing equals less stress. Seine towing, in particular, can benefit from fair tidal flows, but netpen tows are also strongly affected.

Towed Seine

Towed seines should be used only when the towing distance is a mile or less, and the towing speed should be kept to less than 0.25 knots.

During towing, you should ensure that the seine's loose web is spread over a wide area. By rigging the corkline to the bow of the seiner and gathering the net at several points along the length of the vessel, you can distribute the excess net material evenly. And by hanging weights off the side of the vessel, you can counter the propellor wash and the seine's tendency to collapse. Figure 1 shows a one-boat towing configuration.

A two-boat configuration (Fig.8) has been found to be useful for large sets, which require a considerable length of net in the water. The advantage of this configuration is that the net is held open, so the volume within the net is increased, and web folds and bags are, for the most part, eliminated. Physical damage to the fish during towing is thus reduced.

To adopt the two-boat towing configuration, the second boat positions itself beside the cork line about one boat length away from the fishing vessel. The crew then attaches several lines to the cork line and passes a bow line to the bow of the fishing vessel. The second vessel is then towed into position by its power skiff, and the towing configuration is complete.

As with all live transport methods, you transfer herring from towed seine to holding pond by swimming them across a temporary, submerged gate. When a one-boat tow has been used, the following method has been found to work well.

As the fishing vessel under tow approaches the ponds, the running line from the fishing vessel is taken to the pond via power skiff. The end of the running line is secured to the corner of the pond, enabling the vessel to winch itself toward the pond without using its propeller, which could become entangled in the net. As the vessel and net approach the pond, the angle of the vessel to the pond can be adjusted by using the bow thruster, if available.

The vessel is laid alongside bow-to with its stern away from the pond. The gable end of the net is tied along the boomstick and the gable laced to the pond's web at the gate. A wind line holds the cork line near the gable end away from the gate, and a power skiff can stand by to pull out the cork line if the bag of the seine drifts or collapses.

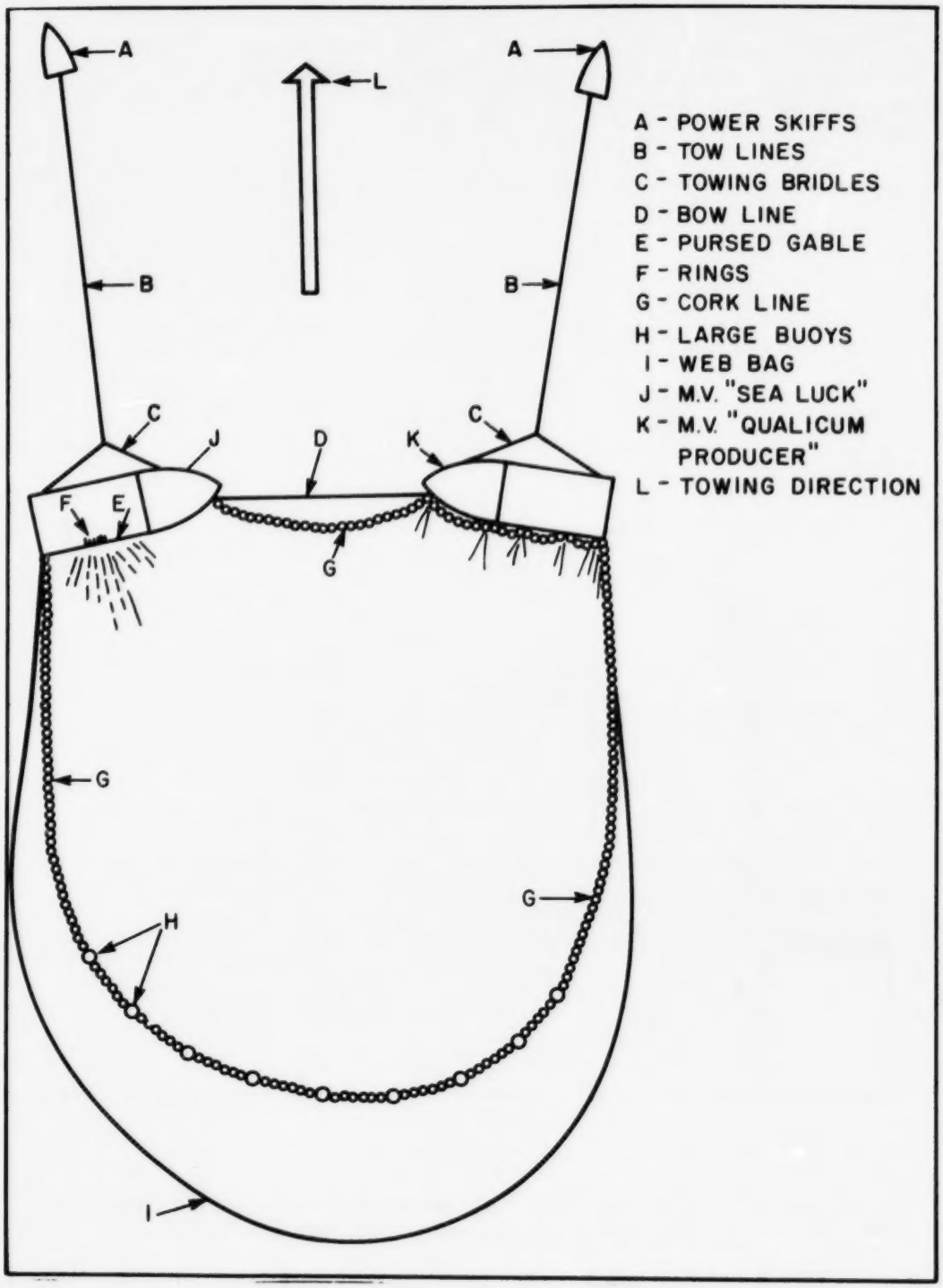

Fig. 8. Two-boat towing configuration.

Source: D.J. Gillis *et al.* 1982. Herring Impoundment and Pumping Operations. Canadian Industry Report of Fisheries and Aquatic Sciences No.130.

To induce the herring to swim through the gate into the pond, the bag size is reduced by drumming in the seine. The gate of the pond is patrolled with gaff and pike pole to prevent unwanted species from entering the pond. When almost all the net is drummed in, the remaining bag is reduced by pulling web aboard the fishing vessel by hand. When most of the herring have entered the pond, the gate is closed and the gable end dropped. Figure 9 shows the configuration.

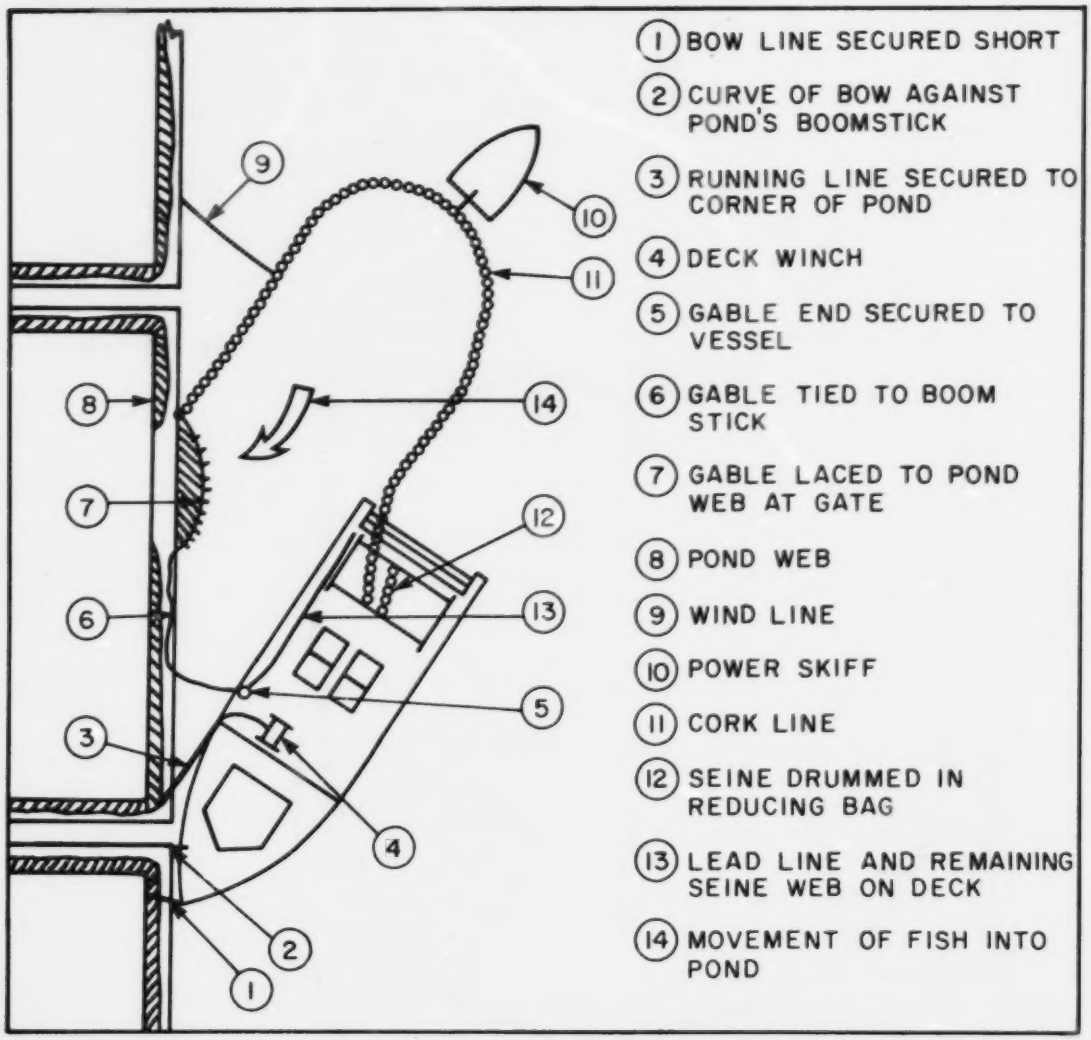
1 BOW LINE SECURED SHORT
2 CURVE OF BOW AGAINST POND'S BOOMSTICK
3 RUNNING LINE SECURED TO CORNER OF POND
4 DECK WINCH
5 GABLE END SECURED TO VESSEL
6 GABLE TIED TO BOOM STICK
7 GABLE LACED TO POND WEB AT GATE
8 POND WEB
9 WIND LINE
10 POWER SKIFF
11 CORK LINE
12 SEINE DRUMMED IN REDUCING BAG
13 LEAD LINE AND REMAINING SEINE WEB ON DECK
14 MOVEMENT OF FISH INTO POND

Fig. 9. Fish transfer to pond using one boat.

Source: D.J. Gillis *et al.* 1982. Herring Impoundment and Pumping Operations. Canadian Industry Report of Fisheries and Aquatic Sciences No.130.

When a two-boat tow has been used, the configuration for transfer is as shown in Figure 10. To transfer herring from the net to the pond, the net must be drummed to reduce the volume of the net and to encourage fish movement towards the pond. Web folds near the stern rollers are inevitable and cause some fish loss. To reduce this loss, the seine net can be retrieved using the power block, hoisted to the top of the boom. Bags of fish can thus be more easily removed from the folds of web and released into the pond with less damage.

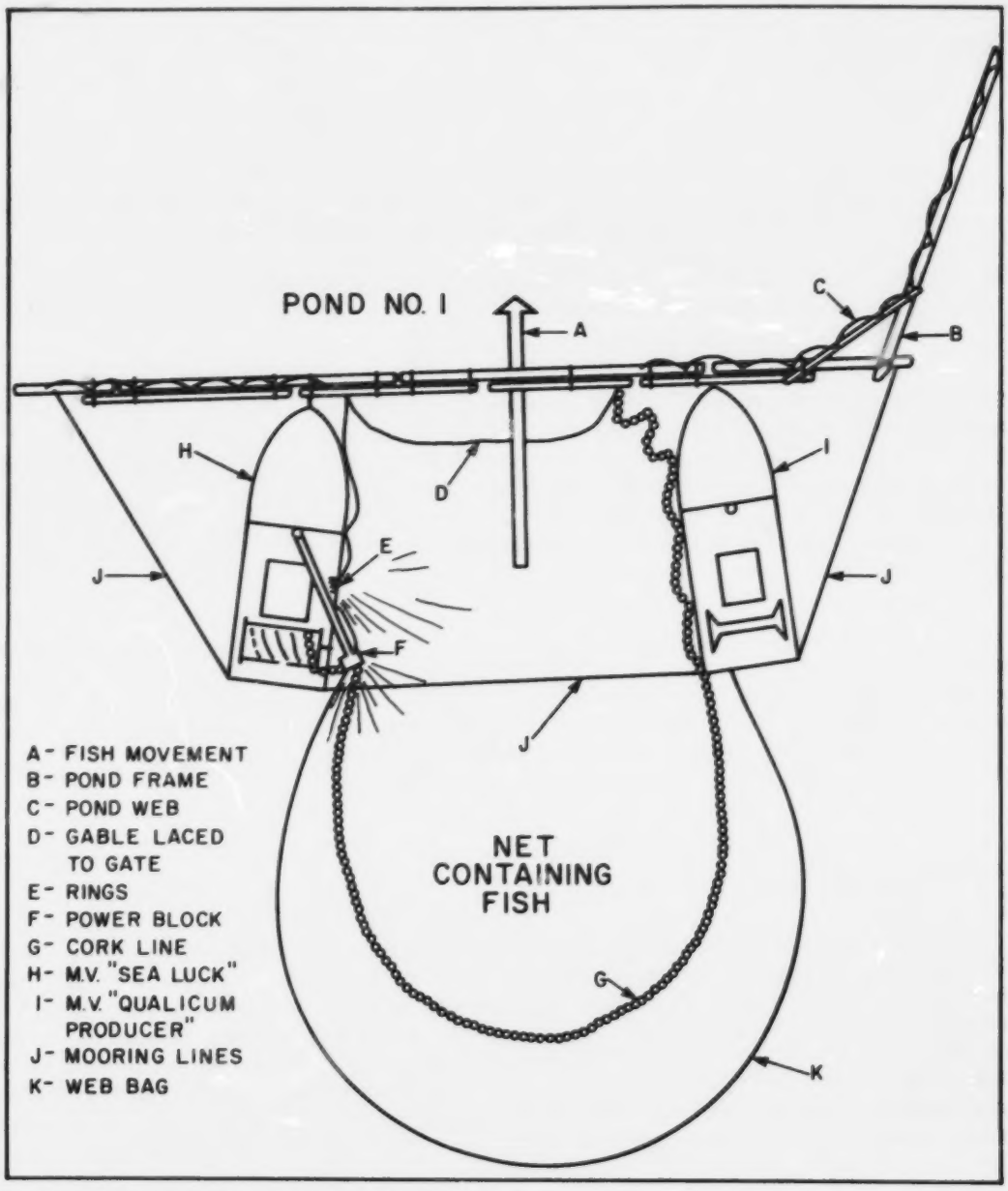

Fig. 10. Fish transfer to pond using two boats.

Source: D.J. Gillis *et al.* 1982. Herring Impoundment and Pumping Operations. Canadian Industry Report of Fisheries and Aquatic Sciences No.130.

Towable Netpen

The netpen is made towable by making the following modifications.

A sailing "bow" is added to the pen's forward entry to improve its towability. This self-shaping dynamic bow is formed by hanging a 100 kg iron ring deep and dead centre in the front of the pen and then releasing the downhaul lines leading to the forward bottom corners. During towing, the water drag folds these corners back while the counter weight holds the front of the pen down, thus forming a V-shaped bow. The iron ring also serves to steady the net and reduce water turbulence.

The netpen float used by the Pacific Biological Station was also modified to provide additional strength for towing purposes: a 610 mm x 101 mm x 9 mm iron corner bracket replaced all existing 177 mm x 152 mm x 9 mm corner brackets; a diagonal reinforcement frame constructed of 63 mm x 9 mm angle iron was attached to the ungated end of the float with galvanized bolts running through the deck, stringers and sleepers (see Fig.3A); the removable gate at the opposite end was fastened securely into position with 75 mm x 203 mm stringers and with galvanized bolts to existing frame stringers.

In addition, the aft end of the actual netpen is usually fitted with a soft cushion of knotless mesh liner to protect the fish. Since the netpen is moved best by being pushed at the midpoint of the aft end, a pushing knee is built onto the aft end of the pen and a small fender of old tires is rigged between boat and float. Once installed, the pen's extra corner braces, hanging anchors and towing fenders are normally left in place. Figures 3(A) and 3(B) show these modifications.

Further construction specifications for converting a netpen for towing can be obtained from the Pacific Biological Station.

The netpen is normally towed to the catch site with all the web pulled up on the decking, and the rigging weights shortened up so as to prevent them from twisting on their pennants while in transit. Boat trailer winches on tripods may be helpful in raising very heavy rigging weights; alternatively, a retrieve-line can be secured to the weights when first installed and used to swing the weights up under the bottom of the float. Slack line from the down-hauls and lifting lines is gathered on the deck. This arrangement gives the structure good mobility and guards against damage to the netpen from contact with bottom in shallow areas, and from floating logs and debris.

When a set is considered imminent, the pen should be prepared by lowering all the rigging into place underwater; two or three crewmen would normally do this in about half an hour. The netpen should be hanging correctly by the time the decision is made to keep the set.

The pen is loaded by manoeuvering it into place alongside the seiner so that it lies alongside on the net side, bow end pointed toward the seiner's stern even with the main deck winch. The positioning is identical to that shown in Figure 2 for the live-barge. The top edge of the netpen is freed at the far end, creating slack, which is pulled under the decking at the seine end, to be stitched fast to the seine to form a gate. Various points on the seine can be used to attach the netpen. One of the most

useful is the breast, where an area of clean web margin can be opened up by sliding some rings out of the way. Once stitched up, the joint should be sunk with a length of chain or other weight. From this point, the seine is handled in the same manner as in loading the live-barge (preceding section). Loading should be cut off when density reaches the desired holding level. The pen should not be overloaded due to the greater risk of descaling at high densities.

Semi-submersible Live-barge

The barge is normally towed empty to the catch site with the ballast tanks dry, as this makes it lighter and easier to manoeuver. Flooding is normally begun before making a set, so the herring can be transferred immediately. After the set, a power skiff or other support vessel manoeuvers the barge into place alongside the seiner, parallel and slightly ahead, so that the stern of the barge lines up with main deck winch. Care must be taken if a stabilizer pole is being used to keep the corks from collapsing as the barge may become entangled in the pole. Spring lines and fenders are rigged to hold the barge in place, with its stern against the seine. The skiffman must continue to tow off slightly, and care must be taken that web does not billow in under the barge, as it will be difficult or impossible to load the barge from below. Ideally, the skiff's tow bridle has a shorter leg running to the bow of the seiner to keep the seine streaming out a bit from the barge.

Depending on the barge design, it may be necessary to fit a portion of the breast of the seine around a flanged loading gate. Alternatively, a section of corkline can be pushed down around the flange. Drumming up the seine then forces the fish out the only escape route, into the barge. Beyond a certain point, drumming merely creates folds in the net; at this time, web must be dried up slowly by hand, to prevent stress and scale loss. Or you might use a power block hoisted to the top of the boom to reduce folds as recommended for transferring herring from a towed seine to a pond. Working with a tonnage of herring similar to what the barge holds is likely to be less troublesome than a huge excess of herring in the set.

Once the barge is loaded to capacity (a matter of judgement, but generally no more than 80 to 100 kg/m^3), the gate is sealed off and towing begins. Tow speeds can range up to 5 knots, with 2 to 3 knots being common. A heavily loaded barge will normally not suffer from low oxygen levels as long as it has adequate access for water exchange via screened ports along the bilges. It may be necessary, however, to keep a heavily loaded barge moving, to avoid oxygen starvation. A small handheld digital oxygen meter would be an inexpensive form of insurance for anyone moving live herring at high densities. At the holding site, the loading process is simply reversed: as the ballast-tanks are pumped dry, the herring leave the rising barge.

HOLDING

Herring should be handled minimally once they are in their holding pen. They become more difficult to handle and become more restless as their maturation date approaches. If you must handle the fish, do so at night when they are less likely to panic.

Continued boil-ups and high-speed swimming are indications of stress. Normally, the fish will swim briskly in the impoundment, but will not appear to be exerting themselves. By timing a few over a measured distance, you can establish whether they are approaching their maximum sustainable speed, which is about 1 knot. Upon seeing signs of stress, the pond operator must determine the stress source and alleviate it before mortality results; it may require the release of some fish. The alternative to taking action—high mortality—is devastating.

Before they spawn, herring display some distinctive behaviours: (1) milling (they no longer swim in unison); (2) papilla extension (a duct is extended from the anal vent, protruding 3 to 5 mm); (3) substrate testing (the fish may be seen swimming on their sides, trailing their belly fins along the surface of the web, or dragging the papilla on the web).

Substrate spawning follows this last stage. The fish twist their bodies into S-shapes touching the pectoral fins and the papilla to a substrate (e.g. the pond webbing), and make short wiggling runs depositing single lines of eggs or milt. One of these stages does not always lead to the next; however, the risk of an accidental spawning always exists until the fish have gone to market. Hence, their behaviour should be monitored. If the fish display the third level of prespawning behaviour, the pond operator may be wise to consider quickly harvesting the fish. There is no other sure method of stopping the spawning.

Density and Catch Estimation

While there seems to be no direct relationship between density of fish and their mortality rate, studies suggest that pen density should remain below 16 kg/m^3 for holding periods of four weeks or less, and under 8 kg/m^3 if the herring are to be held for several months.

In the days following the capture and delivery of the herring, you should adjust the impoundment's density to the desired safe level and cull out injured and small fish. Frequently, small herring will form little schools at the surface of the impoundment and will swim away of their own accord if the top-rope is dropped down a short distance for a few hours. Large valuable herring usually stay down deeper, and will not use the shallow opening to escape.

Overcrowding not only causes a reduction in the amount of dissolved oxygen but also causes high stress levels, scale loss and eroded noses and fins from the fish rubbing against the web. Mature female fish appear to be more sensitive to overcrowding, dying earlier than males or spent fish.

An experienced eye remains the best means of assessing how much herring is in a pond. At the time of writing, work is in progress on hydro-acoustic (sonar) and photo-electric equipment for fish biomass estimation, but further improvements will have to be made to obtain a technique usable at normal ponding densities for marine fish.

If you are using adjoining netpens, you can adjust the herring density within them by moving the herring from one pen to another. The best method is to lace

sections of adjoining netpens together, submerging the joint using a weight and herding the fish from one pen into another by drying up the supply net until enough fish have swum across. The size of openings should be the same as given for fish transfers.

Sampling

You should check 50 to 100 fish per week for at least three weeks after the capture to predict the harvest date and the yield.

The method used to capture herring for sampling depends on the type of holding pond used. For towable netpens such as in Figure 3(C), you can use the method that involves lifting the pen. The procedure can be carried out in about thirty minutes by two people, one on each side of the pen and is performed as follows:

(1) Release all downhaul lines so that the netpen is free to move.

(2) Pull the lifting lines located in the centre area of the pen so as to raise the bottom of the netpen to the surface. This action, which separates the pen into two halves, should be timed to coincide with fish movement up and down the pen. Try to isolate a suitable number of fish in one of the halves.

(3) Crowd the fish by raising the lifting lines one at a time, working towards the end of the pen. As you move to the next lifting line, release the previous one. Once you have suitably crowded the fish, take a representative sample.

This same method can also be used to remove dead fish, except that the bottom of the netpen is not raised to the surface of the water. The original lifting line is kept in a three-quarters-up position while the next one is released and the third is raised. Thus, the live fish are able to escape to the opposite end of the pen while the dead ones roll along the bottom to the end of the netpen. The last section is then fully lifted to remove the mortalities.

For boom-log netpens you can take samples with a dip net by walking out on the boomsticks and catching fish from concentrations near the surface.

For beach ponds, a small seine can be pulled across the pond. Once the herring are captured, the lead line is pulled up until the herring become dense enough to dip-net.

Once you have obtained a reliable sample, you should measure and weigh the fish. Record all the measurements and keep them in a safe place. You will need the following information to predict yield: length and weight of the whole fish, sex, and weight of the gonads. The information is best taken in the above order, since weights are less precise once a fish has been cut open. A simple balance, e.g. kitchen-type or postage-type, will provide basic information; a triple-beam balance, as used in school labs, gives good accuracy. The length information is not essential, but will likely prove useful for verifying the size composition of your catch.

Only one calculation is needed: divide each fish's gonad weight (both ovaries together) by its whole body weight including ovaries and record it as a percentage (e.g.

gonad weight of 30 grams/whole body weight of 150 grams = 0.2, multiplied by 100 gives the percentage, 20%). This result is called the GSI, or gonosomatic index. Good records of these samplings are essential for predicting when to harvest.

Predicting the Harvest

Date: Normally the gonads in impounded herring grow larger week by week at a regular rate. If you know at what size they stop growing and the fish spawn, you can use the GSI information from 3 weekly samples to predict the date of maturity.

The simplest method is to draw a chart on squared paper, with 30 GSI units up the side and days along the bottom. Then, for each of your 3 weekly samples, calculate an average for the GSIs of only the females, and plot it on the chart. Draw the straight line that comes closest to all 3 points; this gives you a visual indication of the rate of roe increase. The mathematical process that does the same thing more accurately is called simple linear regression. Many programmable calculators and home computers can do this very quickly. It's easy to learn, and well worth doing.

By extending the rate-of-increase line, you can forecast the date of maturity. Let's say you are confident that your female herring will stop gaining roe weight at a maximum average GSI of 25. On the chart, you draw a horizontal line from the 25 mark on the GSI scale out to where it meets the line you plotted. A vertical line drawn from this point down to the date-scale gives you the expected date of maturity. (See Fig.11.) You can then plan the harvest date. Research at the Pacific Biological Station indicates that the best Yield of No.1 roe comes about 14 days after the expected date of maturity.

Maximum Average GSI: Most female herring reach a maximum average GSI of between 25 and 30. Once you have fished the same wild stock for a year or two, you will probably know what to expect. If you have no GSI records to refer to, information may be available from local fishery officers or herring researchers at the Pacific Biological Station. If the stock has been fished commercially in the past, the test-bucket (Fisheries and Oceans Standard Volumetric Roe Test) results from that fishery may help. It is easy to convert the test bucket data into GSI's by using the diagram in Figure 12 if you know the test bucket roe percentage and the percentage females in the test bucket. As indicated on the diagram, if the percentage of females is 55% and the test bucket roe percentage is approximately 10, the GSI will be 18.

As you can see from the diagram, if a herring population has a 50:50 ratio of males to females, the maximum average GSI of the females will be about twice the test-bucket percentage. A test-bucket result does not give you the actual maximum GSI, but it does tell you that it rose to at least a certain level. It can therefore tell you that the maximum average GSI was at least, say, 27. Since the test bucket method emphasizes No.1 grade roe, it may underestimate the final result for a stock, particularly if there were many No.2's in the test bucket sample. In the impoundment, some of these No.2's will become No.1's as long as they are large enough to begin with.

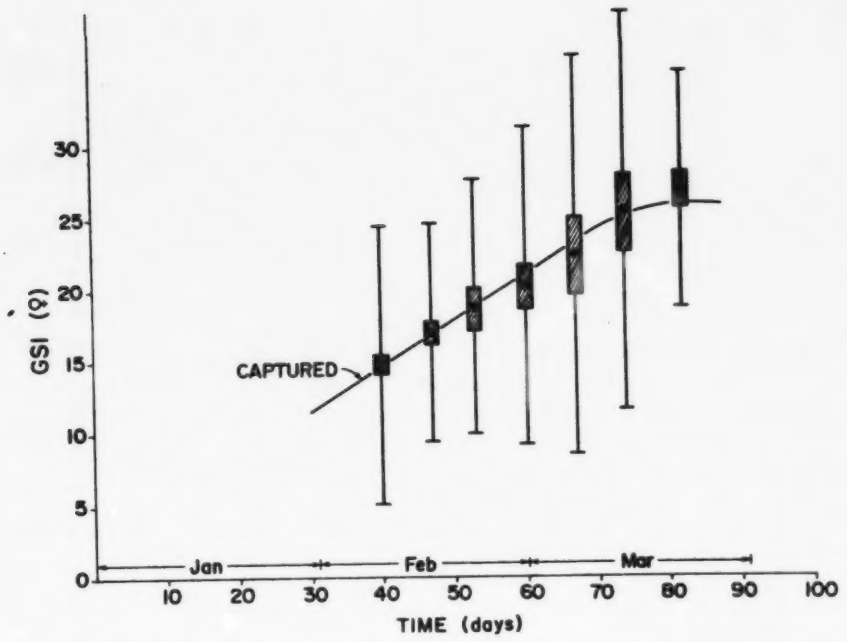

Fig. 11. Progression of GSI Development. This chart shows the regular rate of roe increase in an actual impoundment, which permits the date of levelling off (i.e. maturity) to be calculated in advance.

Source: H. Kreiberg, J.R. Brett and A. Solmie. 1984. Roe Herring Impoundment Research–Report on the 1982/1983 Studies. Canadian Technical Report of Fisheries and Aquatic Sciences No.1261.

Yield: The expected harvest can be calculated from the sex ratio, average size of the female herring and the expected maximum average GSI. Simply multiply the estimated tonnage of herring by the percentage of females; then multiply the result by the GSI. For example, in a 50-tonne impoundment, 45% female, maximum average GSI of 27, you would have 50 x 0.45 x 0.27 = 6.08 tonnes of roe. You must bear in mind that some of this roe may not be No.1 due to small size, and if your sampling has revealed a fraction of immatures, i.e. fish that will not mature until next season, you must reduce the overall tonnage by that amount before making the calculation.

Accuracy: There are some obvious sources of error affecting harvest projections. All the sampling results–ratio of males to females, the average size of females, the average GSI and the rate of roe increase–depend on how truly representative your weekly samplings are. It is important to realize that it is possible for your projections to be wrong even if you sampled and calculated correctly. Thus, it makes sense to sample carefully and to try for 4 or 5 weekly samples rather than the minimum of 3. We do not recommend that you sample more than once a week. High-frequency

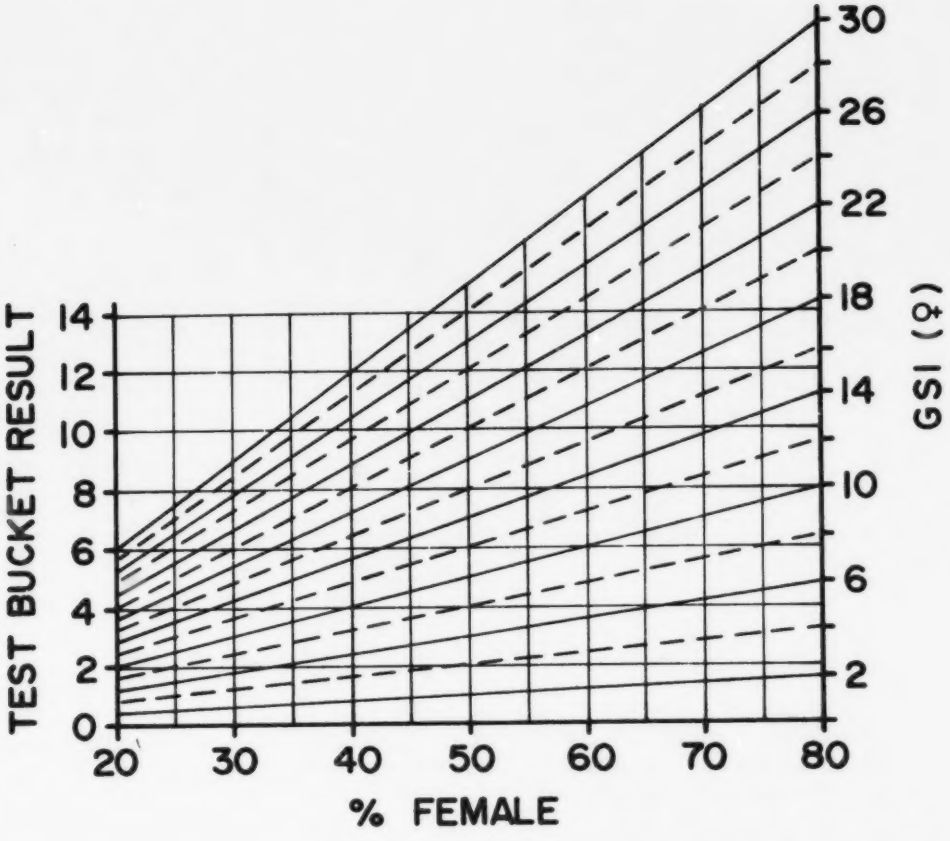

Fig.12. Chart for converting between test bucket results and GSI's (approximately).

sampling gives the fish little time to settle down between disturbances and does not substantially increase accuracy. Good samples are your insurance against mistiming the harvest and against any accidental underassessment at the processing plant.

Monitoring Water Temperature and Dissolved Oxygen Levels

Rising temperature appears to encourage ripe herring to spawn. Research on some herring stocks indicated that spawning is likely to occur above 10°C. While this temperature may not apply to other stocks, an effect likely exists. Therefore, it is to your advantage to monitor water temperature, preferably a little below the surface, on a daily basis and to keep records. If a rise in temperature becomes evident over a few days, it is probably wise to reduce the handling of the herring to a minimum.

Dissolved oxygen level in the pond should remain well above the half-saturation level generally considered the minimum for marine fish, not less than 5 parts per

million. Normally, there is no difficulty with oxygen levels at the recommended loading densities; however, unusual fouling, high density and high temperature could combine to cause a problem. Chemical eye dropper kits (Hach brand or equivalent) can be used to do rough field measurements, or a hand-held digital oxygen metre can be used. Oxygen monitoring is not likely to be a critical element in operating an impoundment, but if it is feasible, it may prove beneficial to do it occasionally.

Maintaining the Pen

A watchman or a guard dog should monitor the pen 24 hours a day. Vandals may otherwise harm the operation, or sight-seers including scuba divers may disturb the fish. Animal predators, even if excluded by adequate nets, can still stress the fish by their presence unless driven off quickly. Since a certain number of fish deaths are inevitable in any impoundment operation, the caretaker should check regularly for dead fish, both floating and sunken. The procedure for removing dead fish from a towable netpen is described in this section under Sampling. In boom-log netpens, the dead can be released by towing the pond to deep water and releasing the purse line that closes the bottom of the pen. The majority of dead herring, up to 90%, will sink after death; thus it is important to check for them regularly.

Dead fish left in the pen rot and release toxic gas, which affects the healthy fish. In addition, predators are attracted, especially dogfish, which can easily chew through the net while eating the dead fish. Thus, mortalities should be removed as soon as possible and disposed of at some distance from the site.

Fish mortality will normally not exceed 5% over an 8 to 10-week holding period. The number of mortalities will taper off as the harvest date approaches, as long as the pond is not overcrowded or bothered by predators. Usually, mortalities cease about the time you wish to reduce or stop handling the fish to prevent accidental spawnings.

Feeding and Covering: Covering to provide shade in the form of a wooden structure does not affect the weight or development of the ovary and does not, therefore, improve the roe yield. But cover provides the observer with an excellent opportunity to study behaviour at all times, and for this reason, is useful. Feeding appears to speed up the maturation and spawning of the herring by about 1 week. It makes no difference to the final roe size, and is unlikely to be cost effective.

Disease: What little disease has been observed during studies to date has been of a bacterial nature related to stress–another reason why the herring must be handled gently and minimally throughout the impoundment. Disease treatment in an impoundment would be highly impractical, so disease prevention is the only solution.

Salinity: Water salinity does not seem to influence the time of spawning nor the roe yield.

Coping with Predators

During impoundment, predation may come from seagulls, crows, herons, bald eagles, otters, minks, sealions, rockfish and dogfish. Sealions may frequent a pond site just after it is stocked, but usually leave within several days. During this time an occasional seal bomb may be useful. It is also essential not to dispose of any dead fish nearby.

The most effective means of combatting predators is with predation and cover nets. Predator nets made of heavy salmon seine web complete with bottom should be hung outside the netpen to protect it against sealions and dogfish in particular. For towable netpens, the predator net is secured to the top inside perimeter of the float. The down-haul lines from the pen pass through the predator web at the bottom corners and at the bottom sides of the predator net opposite the weights used for maintaining the box shape of the herring pen. These weights then hold both nets in a box-like shape while still allowing the herring netpen to be lifted independently of the predator net. Experience has shown that having the netpen nested inside a predator net still permits all normal handling requirements.

Netpen covers made of lighter salmon seine web can be used to keep birds, mink and otter out of the pens. These can be kept from dipping onto the surface of the water by stringing heavy twine across the netpen at 9-m intervals and also by attaching the cover to the centre cross-beam of the float. The covers should be laced tightly on all sides except for a short length where halibut clips can be used to hold it in place. This allows access for removing dead fish or obtaining samples without unlacing. Mink and otters are resourceful and clever; around netpens they can pass through any opening large enough to force a man's open hand through, even if they have to climb up the web from water level.

A predator net panel can also be attached to the underside of the bottom of the netpens to prevent dogfish from chewing on dead fish on the bottom of the pen. The corners of the panel are attached to the downhauls at the netpen corners, providing a space between the netpen bottom and the predator panel (sometimes called a "sharkguard").

Boom-log pens and beach ponds should also be protected by predator nets.

HARVESTING

The most suitable harvest date will depend primarily on roe quality and volume. But market prices and packer availability should also be considered. Careful handling of the herring is crucial to the success of the harvest. Under ideal conditions, the packer will be brought to the pond and the delivery of the entire stock will be immediate.

The best method for harvesting a portion of the stock in large, towable netpens involves swimming some of the fish into a smaller "transfer" pen, complete with its own float. Since it holds fish only briefly, this transfer pen can be built more simply than

the main pond, e.g. out of boom-logs and spare web. The top borderline of the net from the small pen is laced to the top end borderline of the larger netpen, the corners having been released. The lifting lines are then used in the rolling manner described for sampling. This procedure should be carried out with caution and ample time to avoid stresses that might set off a spawning. The milt squeezed out of even a small number of ripe males trapped in a fold could be enough to start some fish spawning. Here, as in other instances, it may be best to do the transfer during the night, before the packer arrives, or plan the entire operation for night-time.

Transfers like this, while still involving stress, are probably less likely to set off spawning than simply crowding the fish in the main pen and brailing or pumping out from that point.

Before actually harvesting the fish, i.e. loading them into totes or holds, you should tow the transfer pen some distance away from the main pen, to avoid any problem with accidental spawning. (Discharge from fish pumps, and even from brailers, will often carry milt from ripe males.) The fish can then be brailed or pumped into totes for transport to processing facilities.

In boom-log netpens and in beach ponds, the herring can be caught using a small bait seine. Each end of the net should be equipped with a gable and purse line, so the bottom of the net can be pursed from both ends. Once the set is made, the seine is dried up until the fish can be brailed or pumped into totes, being careful not to dry up so much that the fish are injured.

Using Brailers

A small conventional brailer is best, measuring perhaps 1.5 m in diameter and 1 m in depth, made of soft, knotless nylon, preferably with 15-mm mesh. The brailer should be loaded lightly, not more than 0.3 m high, to avoid crushing the herring and losing roe.

Using Pumps

Pumping is preferred to brailing because it produces less bruising and red gill covers. If whole herring pumped from seines are to be of high quality, you should make sure that –

- a pump designed for live fish is used wherever possible
- the fish are pumped live if possible
- the pumps and attached fish-carrying pipes are free of abrasive surfaces and are set up so as to cushion the impact of the fish against the packing medium
- the pumping proceeds slowly to reduce damage
- the pumping allows enough water to accompany the fish to facilitate their passage

- discharge from any dewatering unit or seepage from totes and decks, which may contain ripe milt, is prevented from coming in contact with live ponded herring

Damage estimates for fish pumped and brailed are given in Table 4.

Table 4
Damage Estimates for Fish Pumped and Brailed

	Mean % Scale Loss	% With Eye Blood	% With Gill Cover Blood	% With Body Bruises	% With Cuts	% With Abr.
Fish from seine	6.83	18.0	4.0	0.0	0.67	2.0
Fish pumped	10.76	84.6	0.0	7.7	0.0	0.0
Fish brailed	9.48	8.0	24.0	14.0	2.0	0.0

Source: D.J. Gillis, *et al.* 1982. Herring Impoundment and Pumping Operations. Canadian Industry Report of Fisheries and Aquatic Sciences No.130.

Transporting to Processing Facilities

The fish must be handled carefully after death to prevent bruising and scale loss. And they must be chilled immediately to 0°C to slow decomposition and to render them less susceptible to damage.

Using Totes: Totes are the best method of transporting herring to the processing plant. The tote should be partly filled with slush (a mixture of half ice and half sea water), the fish placed on top and then more ice and sea water added to support each fish with the same pressure on all sides of its body. A tote measuring 1 m high by 1 m square at the top should be filled to a depth of between 15 and 25 cm, and contain about 500 lbs of fish. Overfilling will bruise the fish. Comparable amounts should be used for other tote sizes.

Using Champagne: Holds filled with champagne—a mixture of 75% ice and 25% aerated sea water—are considered the second best way to transport fish to the processing plants. The hold should contain about one-third champagne. This method is not as good as using totes simply because of the volume; some fish will inevitably be damaged or not cooled as well as in totes.

WINDING UP OPERATIONS

Once the herring have gone to market, the operation is over for the year. If you plan to use the same site or the same herring stock again, you can take a few steps now to benefit next year's venture.

Tear-down and Storage

The netpen and predator net should be pulled out of the water as soon as possible to minimize fouling and damage by sunlight. It may be easiest to remove the two nets one at a time using the drum of a seiner for power, and it may be useful to wash the nets with a deck hose. If the nets are to be stored dry, all dead herring scraps must be removed. Perhaps the best procedure is to spread the net out on a wharf or other flat surface and wash the entire unit with a pressure hose, while at the same time mending any holes that turn up.

Some bait-pond operators prefer to leave fouled nets on the mud bottom of a channel or bay to be cleaned by natural decay and small scavengers. However, for a larger netpen, which may involve a substantial investment, it is safer to spend a day or two washing and mending. The net should be stored in a rat-proof netbox once it has air dried. The netpen is then ready for next season. Ropes, lines, tensioning weights and other equipment should also be tagged and stored, so that the entire package can be re-assembled next season without confusion.

Floats and logs can be stored on the beach near the high mark for spring tides. Mooring blocks can be left on the bottom with a marker buoy, if not in conflict with other users of the site area.

Records and Analysis

By harvest time, you should have a collection of sampling records on fish size, roe size, rates of development, mortalities removed, water temperatures and possibly a daily log book for the pond. While it is fresh, you should tidy it up and file it for future reference. Analyze your mistakes and sources of problems; and if you or any of the crew have suggestions for improvements, record them now. Good records are sure to pay off in any fishing operation, and particularly so in a new venture like sac-roe impoundment.

APPENDIX 1

ACQUIRING A FORESHORE LEASE

First, contact the Marine Resources Section of the Fisheries Branch in Victoria or Nanaimo, and find out whether you need a lease. If a shore zone lease is required, the upland owner must consent to it. If the upland owner is the Crown, you will generally have no problem. Government maps will give you the legal description and the Land Registry Office will provide you with ownership data.

Second, since the potential lease cannot conflict with existing fisheries activities or navigable waters, you must check with the local fisheries officer and the Coast Guard.

Third, you must prepare a 5-year management plan for the Marine Resources Section to demonstrate that you have a realistic view of the costs, the returns, and the timing of those returns. This plan will become part of the lease contract.

Fourth, you submit the plan to the Ministry of Lands, Parks and Housing once the Marine Resources Section has approved it.

APPENDIX 2

REFERENCE AIDS

1. GLOSSARY

BEACH POND	an impoundment formed with mesh curtains hanging from floating logs and touching the sea-bottom; the sea-bottom serves as the bottom of the pond
BOIL-UP	the rapid, swirling and irregular movement of a group of fish when disturbed which causes the water surface to froth
BRAILER	a small dip net that resembles a purse seine in that the bottom can be opened and closed
CHAMPAGNE	a mixture of ice and aerated sea water used for packing fish
DIP NET	a hand net used to scoop fish out of the water
FLOAT	a floating structure used to support a web enclosure for holding live fish
FOULING	kelp, other algae and diatoms which, over a period of time, gather on the nets and inhibit spawning
GONAD	an organ in which reproductive cells develop; ovaries and testes are gonads
GONOSOMATIC INDEX	gonad weight as a percentage of the total body weight of a single fish
IMMATURE	refers to a female herring at or near spawning time with a GSI of 10% or less and males with a GSI of 5% or less; unlikely to mature until the following season
IMPOUNDMENT	the process of holding or shutting up fish in an artificial pond while they mature; a structure which achieves this
MORTALITY	the number of fish deaths usually expressed as a percentage of the initial amount of fish, by weight

NETPEN	the web enclosure that confines the fish; provided with a web bottom, and usually suspended in the water from a moored floating framework
ROE	fish eggs; also called spawn
SAC-ROE HERRING	Pacific herring destined for processing to extract whole roe
SALINITY	salt content of water expressed as parts salt per thousand (p.p.t.) of water; normal sea water ranges from 25 to 30 p.p.t.
SOUND	to go to the bottom; dive
SPENT	a mature fish that has finished spawning; a slink
TIME SERIES	charted results of periodic fish sampling
TONNE	a metric measure of volume; one tonne equals 1000 kilogrammes, or 2200 lbs
TOTE	a container used to pack fish for transport
TURBIDITY	particulate matter suspended in water, reducing visibility

2. REPORTS

The following reports describe research results to date for herring impoundment or provide details of herring biology.

Brett, J. R., and A. Solmie. 1982. Roe herring impoundment research - report on the 1980-81 studies. Can. Tech. Rep. Fish. Aquat. Sci. No. 1061. 51 p. (Pacific Biological Station).

Gillis, D. J. 1979. Ponding and other factors affecting the quality of herring for the food industry. Dept. Fish. and Oceans Ind. Rep. No. 109. 39 p. (DFO Field Services Branch, 1090 West Pender Street, Vancouver, B.C. V6E 2P1.)

Gillis, D. J. *et al.* 1982. Herring impoundment and pumping operations - factors affecting the quality of roe herring products. Can. Ind. Rep. Fish. Aquat. Sci. No. 130. 61 p. (DFO Field Services Branch, 1090 West Pender Street, Vancouver, B.C. V6E 2P1).

Hourston, A.S. and C.W. Haegele. 1980. Herring on Canada's Pacific Coast. Can. Spec. Publ. Fish. Aquat. Sci. No. 48. 23 p. (Pacific Biological Station)

Kennedy, W.A. 1978. A Handbook on Rearing Pan-size Salmon Using Floating Seapens. Dept. Fish. Env., Fish. Mar. Serv. Ind. Rep. No. 107. 111 p. (Pacific Biological Station)

Kreiberg, H., J. R. Brett, and A. Solmie. 1982. Roe herring impoundment research - report on the 1981-1982 studies. Can. Tech. Rep. Fish. Aquat. Sci. No. 1149. 45 p. (Pacific Biological Station).

Kreiberg, H., J. R. Brett, and A. Solmie. 1984. Roe herring impoundment research - report on the 1982-1983 studies. Can. Tech. Rep. Fish. Aquat. Sci. No. 1261. 31 p. (Pacific Biological Station).

Kreiberg, H., J. R. Brett, and A. Solmie. 1984. Roe herring impoundment research - report on the 1983-84 studies, and final report. Can. Tech. Rep. Fish. Aquat. Sci. No. 1329. 31 p. (Pacific Biological Station).

MacGregor, Mary. 1982. "An Economic Assessment of the PBS Roe Herring Impoundment Project", Pacific Biological Station Working Paper. 15 p.

3. LIBRARIES

The reports listed above may be found in the following libraries.

DFO West Vancouver Lab, 4160 Marine Drive, West Vancouver, B.C., V7V 1N6

Institute of Ocean Sciences, 9860 W. Saanich Road, P. O. Box 6000,
Sidney, B.C., V8L 4B2

McPherson Library, University of Victoria, Victoria, B.C., V8W 2Y3

Pacific Biological Station, Nanaimo, B.C., V9R 5K6

University of British Columbia, Institute of Animal Resource Ecology, 2075 Wesbrook Mall, Vancouver, B.C., V6T 1Y3

University of British Columbia Library, 1956 Main Mall, Vancouver, B.C., V6T 1Y3

APPENDIX 3

ABBREVIATIONS USED IN THIS HANDBOOK

C	centigrade
cm	centimetre
cu	cubic
F	fahrenheit
ft	foot
GSI	gonosomatic index
in	inch
kg	kilogramme
km	kilometre
L	litre
m	metre
mi	mile
mm	millimetre